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FINAL REPORT

CONTRACT NAS8-33465

COMMERCIALIZATION OF THE POWER FACTOR CONTROLLER

PREPARED BY
IVECO, INC.
5762 RESEARCH DRIVE
HUNTINGTON BEACH, CA 92647

FOR
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812
APRIL 15, 1981

Edward Yrisarry, Jr., P.E.

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   U.S. Department of Energy
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2 Instruments & Control Systems - December 1979
   James V. Yu, "Motors and Your Electric Bill"

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   Frank Nola, "Power Factor Controller"
1.0 INTRODUCTION

This is a final report culminating a design/study program for "Commercialization of the Power Factor Control Unit", NASA contract No. NAS8-33465 between NASA/MSFC, Huntsville, Alabama, and IVECO (Improvement Via Electronics), Huntington Beach, California. The contract was a Cost-Share type wherein IVECO (the contractor) was reimbursed for not more than 34.9% of the cost of performance under the contract. Total liability of NASA was $38,310.00, with a total performance limitation of $109,754.00. Deliverable end-items under the terms of the contract were six (6) packaged single-phase controllers capable of accommodating up to 5 HP at 240V, and twelve (12) packaged three-phase controllers capable of accommodating 10 HP at 480V, plus this final report. The Scope of Work is delineated in Exhibit "A", paragraph III.B.5 of the contract. The contract work statement, referred to above, is delineated in its entirety in Appendix A of this report. Table 1 is a list of the items requiring determination as a result of this contract. Appendix B shows the reporting requirements of this contract.

<table>
<thead>
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<th>TABLE 1</th>
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<tr>
<td>TO BE DETERMINED</td>
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<tr>
<td>o POTENTIAL THIS CIRCUIT HAS FOR SAVING ENERGY</td>
</tr>
<tr>
<td>o COST TO PRODUCE THE DEVICE - BOTH SINGLE AND 3 PHASE</td>
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IVECO INC.
IMPROVEMENT VIA ELECTRONICS
**TABLE 1 (CONT.)**

- Can the device aid in cutting costs charged for a poor power factor? Can it replace capacitors and synchronous motors used for correction.

- In certain applications can the device double as the power contactor for the motor?

- Can the device serve as a means of limiting starting inrush current in large motors?

- Potential for reducing air conditioning costs.

- How serious is the problem of connecting to the wye point of 3 phase wye motor?

- Is the wye point available in larger motors?

- Effect on utilities distribution system

- Is the savings to the utility company significant?

- Stability needs to be analyzed

- Ability to respond to step type loading needs to be studied and improved

- In some cases the capacitor required for stability needs to be larger than that required for filtering. This slows the response.
In addition, preliminary investigation and UL approval by Underwriters Laboratories, Inc. on the design and packaging components of the hardware developed under the contract was a requirement. This is still underway. The UL technical submittal is included with this report as Appendix C. IVECO selected seven (7) separate industrial/public sector organizations for installation, testing, and demonstration of the effectiveness of the controllers developed. Three (3) of these installations involved single-phase motors, and the other four (4) involved three-phase motors. Difficulties during the course of field testing have resulted in several iterations of the three-phase controllers. Not all testing was completed at contract duration end (12-31-80); however, the unfinished tests will be accomplished by IVECO and an addendum will be furnished to NASA/MSFC. The tests are expected to be completed by 6-30-81. Section 4.0 of this report discusses the tests completed and their results thus far.

At the outset of the program, IVECO identified areas of design/development previously undertaken by IVECO (i.e. prior to contract) which are directly applicable to the controllers and involved proprietary designs. Such areas of development were identified in Paragraph I "DESCRIPTION OF ORGANIZATION PERFORMANCE", of Report No. 1. The IVECO prior achievements are listed below (excerpt from Report No. 1):

A. The controller can be used on either "delta" or "wye" wound motors.
B. No physical connection to the motor "neutral" is necessary.

C. The controller can be placed physically distant from the motor of application (i.e., at a convenient junction box).

D. Current sensing in lieu of voltage sensing is employed to minimize heat dissipation.

E. A single adjustment only is necessary to set up all three phases of operation.

F. Motor balance is accomplished by relating each phase control to the other two phases.
2.0 GENERAL DISCUSSION

Electric motors are devices that convert electrical energy into mechanical energy, sometimes efficiently, sometimes not efficiently.

Figure 1 shows an electric motor family tree. The overwhelming majority of all AC motors employed are AC induction squirrel-cage motors. There are approximately 99,000 different combinations of characteristics (end-class) of AC squirrel-cage induction motors in the 1/6 to 500 HP range. Figure 2 shows a breakdown of these classifications. Total end classification of all motors would probably run into hundreds of thousands. Figure 3 shows the percentage of annual energy use of electric motors by end users. Figure 4 shows the percentage of electrical energy consumption by motors by user categories.

Approximately 58% of all U.S. electrical energy is used to power approximately 750 million motors in this country. In the non-residential sectors of the U.S. economy, this percentage rises to 80%; more than 90% in industries such as mining, primary metals, and electric utilities themselves.

Ninety percent of the motor population, however, are small fractional horsepower units used principally in households. They, surprisingly, account for only 2 1/2% of the total motor drive energy use. The 5 to 125 HP range, constituting only 1.8% of the motor population, accounts for almost one-half of the
Figure 1 Electric Motor Family Tree
Figure 2 Classification of Squirrel-Cage AC Induction Motors
Figure 3
Percentage of Annual Electric Energy Use By Electric Motors
By End User Category
Figure 4
Percentage of Electric Energy Consumption
By Electric Motors By User Category
total motor drive energy use.

2.1 POWER FACTOR

Motor efficiency is a measure of the mechanical work output versus electrical power input. A motor's efficiency is the percentage of electrical energy put into mechanical work. The remainder is heat loss, typically referred to as "watts loss". A motor's power factor measures how much current it draws. A motor uses real power (measured in kilowatts) to perform work, and reactive power (measured in volt-amperes-reactives, or VAR's) to provide a magnetizing force. These two (2) power components form a right-angle triangle which is shown in Figure 5. The hypotenuse of the triangle is apparent power (measured in volt-amperes). The power factor is the ratio between real power and apparent power (kW/kVA) expressed as a percent. The cost of operating a motor depends on both its efficiency and its power factor. Efficiency determines how much is charged for the real power needed to run the motor. Often, an electric utility charges penalties for power factors below 85% and/or a kVA demand. This is because an electric utility must generate the total current (kVA) needed, but is paid only for kW consumed. For example, if a motor has a low power factor, the utility must provide more kVA capability than would otherwise be required; thus, a penalty is charged.
When load on a motor decreases, say from full load to no load, the power requirement decreases, but the angle increases, thus causing a decreasing power factor. As can be seen in the figure, while watts decrease, VAR's increase, and the percentage of power waste increases. This phenomenon can better be seen in Figure 6, load versus power/load versus power factor curves. For example, as load decreases from 100% to zero (0), power may typically reduce from 100% to 35%. The same figure shows that, while the power factor at full load may be 0.9, it deteriorates to 0.2 in some motors.
Figure 6
Load vs Power - Load vs PF Curves

2.2 THE MOTOR POWER CONTROLLER CONCEPT

The basic concept of the motor power controller (power factor controller) is to take advantage of an elemental motor action phenomenon. As load on a motor changes, there is a phase relationship change between the current and the voltage. This phase change is what causes the change in power factor. Power factor deteriorates with decrease in load and is maximum at full load. Since the power line can be considered an infinite voltage force, voltage remains constant and current is variable. Thus, current is proportional to load. A current monitor, therefore, provides an indication of loading conditions on the motor. The concept of the motor power controller is depicted in Figure 7.
A triac (an electronic switch) is placed in series with the motor current. One (1) triac is required for single-phase motors, and three (3) triacs for three-phase motors (i.e., one (1) triac in each current leg of the motor). The triac, which is a solid-state switch, blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac switch remains ON until the current goes through zero (0). Current does not flow again until the gate voltage is again applied. Thus, the RMS voltage across the motor can be reduced (triggering the triac gate at a given point during the operating cycle) and allowing the triac to switch OFF as the current goes through zero (0). There are definite advantages to using a triac (or SCR).
as a static switch in AC circuits. It allows the control of relatively high currents with a very low power control source. Since the triac "latches" each one-half cycle, there is no contact bounce. Also, since the triac always opens at zero (0) current, there is no arcing or transient voltage developed due to stored inductive energy in the load or power lines. Appendix D encompasses NASA Tech Brief MFS-23280 describing the Power Factor Controller (herein referred to as the Motor Power Controller).

2.3 SAVING ENERGY WITH THE MOTOR POWER CONTROLLER

The basic questions here are: Can control of power factor (i.e., improvement) significantly affect energy consumption in motors? Has this contract demonstrated that applying the motor power controller to existing motor installations really reduced energy consumption primarily from the standpoint of user cost?

Table 2 shows the potential that, based on varying duty cycles of a motor, the power factor control can save energy. Equation 1 and its associated assumptions provide the derivation for the data in Table 2. The efficiencies shown below were obtained from the U.S. Department of Energy, Report No. DOE/CS-0147. Paragraph 3.11 of this report provides significant insight into the potential savings suggested here.
<table>
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<tr>
<th>Duty Cycle</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>1.82</td>
<td>2.25</td>
<td>2.68</td>
<td>3.12</td>
<td>3.56</td>
<td>4.00</td>
<td>4.44</td>
</tr>
<tr>
<td>20%</td>
<td>2.00</td>
<td>2.50</td>
<td>3.00</td>
<td>3.50</td>
<td>4.00</td>
<td>4.50</td>
<td>5.00</td>
</tr>
<tr>
<td>30%</td>
<td>2.20</td>
<td>2.70</td>
<td>3.20</td>
<td>3.70</td>
<td>4.20</td>
<td>4.70</td>
<td>5.20</td>
</tr>
<tr>
<td>40%</td>
<td>2.40</td>
<td>2.90</td>
<td>3.40</td>
<td>3.90</td>
<td>4.40</td>
<td>4.90</td>
<td>5.40</td>
</tr>
<tr>
<td>50%</td>
<td>2.60</td>
<td>3.10</td>
<td>3.60</td>
<td>4.10</td>
<td>4.60</td>
<td>5.10</td>
<td>5.60</td>
</tr>
<tr>
<td>60%</td>
<td>2.80</td>
<td>3.30</td>
<td>3.80</td>
<td>4.30</td>
<td>4.80</td>
<td>5.30</td>
<td>5.80</td>
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<tr>
<td>70%</td>
<td>3.00</td>
<td>3.50</td>
<td>4.00</td>
<td>4.50</td>
<td>5.00</td>
<td>5.50</td>
<td>6.00</td>
</tr>
<tr>
<td>80%</td>
<td>3.20</td>
<td>3.70</td>
<td>4.20</td>
<td>4.70</td>
<td>5.20</td>
<td>5.70</td>
<td>6.20</td>
</tr>
</tbody>
</table>

Note: The table data represents potential kW savings for various duty cycles. The values are approximate and may vary depending on specific conditions.
Eq. 1: \[ P(kW) = \frac{\sqrt{3} (I)(V)}{10^3} = \frac{(0.746) \text{ Hp}}{\text{(p.f.) (eff)}} \]

Assuming:

(a) \((\text{p.f.})_{FL}\) at \(30^\circ = \cos 30^\circ = 0.866\)

(b) \((\text{p.f.})_{3/4L}\) at \(45^\circ = \cos 45^\circ = 0.707\)

(c) \((\text{p.f.})_{1/2L}\) at \(60^\circ = \cos 60^\circ = 0.500\)

(d) \((\text{p.f.})_{1/4L}\) at \(75^\circ = \cos 75^\circ = 0.259\)

(e) \((\text{p.f.})_{NL}\) at \(80^\circ = \cos 80^\circ = 0.174\)

Efficiencies:

<table>
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<th>HP</th>
<th>Efficiency$^1$</th>
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<tr>
<td>1</td>
<td>0.650</td>
</tr>
<tr>
<td>1 - 5</td>
<td>0.770</td>
</tr>
<tr>
<td>5.1 - 20</td>
<td>0.825</td>
</tr>
<tr>
<td>21 - 50</td>
<td>0.875</td>
</tr>
<tr>
<td>51 - 125</td>
<td>0.910</td>
</tr>
</tbody>
</table>

Duty cycle is defined as the percentage of time that the motor is under load during one complete operational cycle. Since various motor applications exhibit various motor load profiles, it would be impossible to assume all possible conditions; therefore, the data shown in the Table assumes that a motor is either under full load or no-load. For example, 60% duty cycle means that the motor is under full load 60% of the time and under no-load 40% of the time. Figure 8 shows, in detail, the estimated motor population and electrical energy consumption by user category and SIC code.$^1$ Appendix E lists the SIC codes for end user categories.
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IVECO INC.

24

IMPROVEMENT VIA ELECTRONICS


### Estimated Motor Population And Electricity Consumption (1977)

(Motors in Transportation Equipment Excluded)

**Table 8b**

<table>
<thead>
<tr>
<th>Use Category</th>
<th>IRC</th>
<th>(5V-125) hp</th>
<th>Greater than (125) hp</th>
<th>(3V)</th>
<th>(10V)</th>
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<tbody>
<tr>
<td><strong>Units</strong></td>
<td><strong>Motor Drive</strong></td>
<td><strong>Total</strong></td>
<td><strong>Units</strong></td>
<td><strong>Total</strong></td>
<td><strong>Percent</strong></td>
</tr>
<tr>
<td><strong>(000's)</strong></td>
<td></td>
<td><strong>(000's)</strong></td>
<td><strong>(000's)</strong></td>
<td><strong>(000's)</strong></td>
<td><strong>Total</strong></td>
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<td><strong>Use Avg.</strong></td>
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<td><strong>(kW)</strong></td>
<td><strong>(kW)</strong></td>
<td><strong>(kW)</strong></td>
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<tr>
<td><strong>(kW)</strong></td>
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<td><strong>(kW)</strong></td>
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<td><strong>Electric Conc.</strong></td>
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<td><strong>(kW)</strong></td>
<td><strong>10^4</strong></td>
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**Agricultural**

**Mining**

**Construction**

**Mfg. Non-Durable**

- **Food**
- **Textiles**
- **Paper**
- **Chemicals**
- **Petroleum**
- **Rubber**

**Mfg. Durable**

- **Furn. Lumber**
- **Stone**
- **Prim. Metal**
- **Fab. Metal**
- **Non-Elec. Mach.**
- **Elec. Mach.**
- **Trans. Equip.**
- **Other**

**Trans. Comm. Util.**

**Trans. Comm.**

**Pipelines**

**Elec. Util.**

**Gas Util.**

**Water**

**Irrigation**

**Commercial**

**Wholesale**

**Retail**

**Fire**

**Pub. Adm.**

**Services**

- **Hotels**
- **Per. Serv.**
- **Auto**
- **Recreat.**
- **Medical**
- **Educational**

**Subtotal: All Except Nihls**

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<th><strong>1,673</strong></th>
<th><strong>1,227</strong></th>
<th><strong>899</strong></th>
<th><strong>564,327</strong></th>
<th><strong>89,264</strong></th>
<th><strong>1,175,282</strong></th>
<th><strong>1,464,100</strong></th>
<th><strong>80</strong></th>
<th><strong>0.4</strong></th>
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**Households**

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<th><strong>1,703</strong></th>
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<th><strong>1,464,100</strong></th>
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**Total**

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<th><strong>1,703</strong></th>
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<th><strong>1,464,100</strong></th>
<th><strong>80</strong></th>
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**Avg. An. Units Consumed**

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<th><strong>34.3</strong></th>
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**Avg. Life**

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**Rounded Total Units**

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<th><strong>800,000</strong></th>
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<th><strong>1,464,100</strong></th>
<th><strong>80</strong></th>
<th><strong>0.4</strong></th>
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**Avg. Life (yr)**

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<th><strong>26.33</strong></th>
<th><strong>26.8</strong></th>
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</thead>
</table>

**Weighted Avg. Size (hp)**

<table>
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<th><strong>68.7</strong></th>
<th><strong>212</strong></th>
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**Avg. Efficiency**

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<th><strong>0.94</strong></th>
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**Avg. Load**

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<th><strong>0.90</strong></th>
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Figure 8b
3.0 TECHNICAL DISCUSSION

This section of the report delves into the technical detail of the motor power controller. Operational descriptions are followed by separate and specific detailed discussions on each of the pertinent paragraphs of the NASA Work Statement.

3.1 THEORY OF OPERATION - SINGLE-PHASE MOTOR POWER CONTROLLER

Power losses in a motor are reduced by sensing the phase lag between the motor voltage and current and making corrections as these parameters tend to change their relationship with respect to each other. This information is fed to the electronic controller which forces the motor to run at a constant predetermined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (i.e., triac or the equivalent) which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac remains ON until the current goes through zero (0). Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to the motor, the gate is triggered at a given point during the cycle, and the device switches OFF as the current goes through zero (0).

The reactive volt-amps of an induction motor is high when the motor is unloaded or partially loaded. Some motors tested showed unloaded current to be about 90 percent of the rated load current.
These currents cause heat losses in the motor.

Since the current remains high in an unloaded motor, the phase between the voltage and current shifts with load. Typically, the current may lag the voltage 80 degrees in an unloaded motor and 30 degrees when loaded. Figure 9 shows how the power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference between the two produces an error signal which biases a ramp voltage that is in sync with the 60 hertz line voltage. The intersection of the ramp and the error voltages is detected by a squaring amplifier whose output provides the time for turning-ON a triac (or SCR's) in the motor line.

Thus, the ON time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the timing diagram of Figure 10.

The phase angle shown as \( \theta \) in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

When the circuit is in control of the motor current, voltage is applied to the motor for a portion of each positive and each
Figure 10
Timing Diagram
negative half cycle of line voltage by means of the solid-state switch (triac) as seen in the timing diagram.

When the triac switches ON, rapid rise of the current is prohibited by the inductance of the windings. The current rises, reaches a peak, and then follows the voltage down as it approaches zero (0), but with a finite lag. Although the firing voltage to the triac goes to zero (0) when the line voltage goes through zero (0), the triac inherently will remain ON until the current goes through zero (0). This is shown by the motor voltage waveform.

The phase lag between voltage and current is indicated by "θ" in the timing diagram. This is the parameter which is to be measured and controlled. The line voltage and its inverse are squared by squaring amplifiers as indicated by E and E in the timing diagram. Each current pulse is squared by similar amplifiers as indicated by I and I'. By "AND'ing" E with I, and E with I' and then "OR'ing" the two, a pulse train is produced which has a pulse width proportional to the phase angle between voltage and current. When acted on by a low pass filter, the dc or average value of this voltage will be proportional to the phase angle. This voltage is summed with a command voltage from P1 (Electrical Block Diagram) which is indicative of a desired phase angle. The difference of the two is the system error voltage. This error is compared with a ramp which is synchronized with the zero crossings of the
line voltage. The intersection of the sloped portion of the ramp and the error voltage are detected by the comparator Q2 and form the turn ON pulse for the triac.

As the load on the motor is decreased, the slight change in phase angle causes the error to drop and intersect the ramp at a lower point. This moves the firing pulse to the right, along the sine-wave, causing the triac to turn ON for a shorter duration, lowering the applied voltage. Conversely, an increase in load will cause the firing angle to move to the left and apply more voltage to the motor. Thus, a phase angle is commanded and the high gain of the feedback loop will vary the applied voltage to force the motor to operate at the desired phase angle regardless of load. Since the current is never higher than that required for a given load, motor losses are minimized.

A detailed electrical schematic of the EY1021 Motor Power Controller is shown in Figure 11. Resistor R 8 and Capacitor C 4 are used to reduce the EMI and RFI effects of the triac (or SCR) switching.

The difference in unit make-up for various horsepower involves changing triacs to accommodate larger current values and apply outside heat sinks commensurate with the power dissipated in the large triacs as a function of the motor horsepower. A chart showing triac versus horsepower is provided in Appendix F.
Figure 11
Detailed Electrical Schematic

Model EY1021 Motor Power Controller

IVECO INC.
IMPROVEMENT VIA ELECTRONICS
Appendix G is a copy of the patent covering the power factor controller (Patent Number 4,052,648).

3.2 THEORY OF OPERATION - THREE PHASE MOTOR POWER CONTROLLER

A block diagram of the three-phase motor power controller is shown in Figure 12.

The philosophy of operation is similar to the single-phase motor power controller. In essence, the voltage and current of each phase is monitored and controlled.

In three-phase control, each of the three phases must be maintained in isolation from each other, yet in order to assure balanced control, the three phases must somehow be related. This is accomplished in the controller by electronically isolating voltage sensing, current sensing, and triac drive. With this isolation, the electronics can then relate phases to each other.

It is important to assure that control is balanced among the three phases so that under-controlling the motor phase currents remain balanced. This means that control of any phase must be related to the other two. Balance must also be maintained between ON-OFF demands positive to negative one-half cycle.

The three line voltages and currents are first squared-up and summed, thus producing a signal proportional to the phase angle between the current and voltage, indicative of the designed phase angle. The output error signal biases a ramp voltage.
Figure 12 Block Diagram - Three-Phase Motor Power Controller
that is synchronized with each appropriate 60 Hz (50 Hz) line voltage. The intersection of the ramp with the error voltage is detected in three squaring amplifiers and the outputs provide the turn-ON of the triacs.

One of the intrinsic values of the technique employed is that all switching is done at zero (0) current. From the distribution line standpoint, this is extremely important. One can see that if, in a plant employing thousands of motors, switching were to occur during heavy current flow, electrical havoc would prevail on the distribution line. As it is, since all switching is done at zero (0) current, no transients are seen on the distribution line. Odd harmonics are, however, of concern. The purpose of the snubber circuit (RC network across the triacs) is to minimize these effects. The biggest concern involves the effect in on-line computers due to switching harmonics. Spectrum analysis has shown that the odd harmonics, due to triac switching, deteriorate in magnitude at a rate fast enough so that sensitive on-line equipment is not effected. IVECO has not seen, in any single instance, complaints of computer anomalies resulting from the motor power controller operation. All computers are designed with filtering sufficient to attenuate harmonic frequencies resulting from the normal ON-OFF switching of heavy equipment in factories (industries).

3.3 SALIENT TECHNICAL GUIDELINES OF THE MOTOR POWER CONTROLLERS

The electronic control design is only one of the major
technical hurdles which had to be accomplished. There are two (2) others: (a) triac current capability during start-up, and (b) thermal dissipation of current through the triacs.

3.3.1 Triac Current

Appendix H shows typical current capability curves of 15, 25, 30, 40, 60, and 80 ampere triacs. These curves show extremely high turn-ON characteristics of the triacs; however, such turn-ON characteristics are shortlived, i.e. one (1) cycle. It is impossible to start a motor in one cycle. Most motors require three to five seconds to reach operating speed. The rapid roll-off of the current capabilities of triacs require some knowledge of both the triac characteristic and motor start-up current requirements in order to assure that start-up can be achieved without loss of the triac switching elements. As an example, the current capability of a 40 amp (I_T) triac at 180 to 200 cycles (3 seconds) is about 100 amps. A 20-horsepower, 480-volt, motor typically exhibits a 108 amp constant current starting requirement to three seconds after turn-ON. This triac would fail turn-ON. Thus, a larger triac must be used or two triacs in parallel must be employed.

Tests have been made using parallel triacs for current sharing. Since it is impossible to have simultaneous turn-ON, investigations concerning the differences in turn-ON of two triacs in parallel, when gated-ON simultaneously, were made. The tests showed that both triacs could be expected to turn-ON (with
proper gate pulses) within a few microseconds of each other. In the example above, two 30A triacs would well survive turn-ON since each triac is capable of 300A at one-cycle (i.e., 8.33 ms). By the time the second triac came-ON, the first one would still be in its 300A surge current range. In terms of current sharing after turn-ON, tests show that without selection, the triacs will share at a rate no worse than 60-40.

3.3.2 Thermal Design

In terms of thermal capability, the design for thermally dissipating the heat caused by the current through the triac is not an overly complex problem; however, triacs will not survive more than 115°C at their substrate junctions, thus the guiding design parameter is to maintain junction temperatures below 115°C. When the motor is operating at full load, current flow through the triac is maximum. Example: Typically, a triac voltage drop is between 1.2 and 1.5 volts at full load current. A 40-amp triac, operating at 40 amps constant current would dissipate 48 watts at the junction. In a three-phase controller, the total heat generated at the triac junctions would be 144 watts total. The heat sink must dissipate heat generated in the switch, such that the junction would not exceed 115°C.

Table 3 is a heat sink chart showing all of the parameters of concern for three-phase controllers from 1 HP through 30 HP, in both 240 and 480 volts. Appendix J is the thermal analysis which
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<tr>
<th>HP</th>
<th>240 VAC</th>
<th>5 HP</th>
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<th>480 VAC</th>
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<th>20 HP</th>
<th>480 VAC</th>
<th>30 HP</th>
<th>480 VAC</th>
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<th>240 VAC</th>
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</tbody>
</table>

**TABLE 3: HEATSINK CHART - 3D**

<table>
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<th>HP</th>
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<th>5 HP</th>
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<th>480 VAC</th>
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<th>40 HP</th>
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<td></td>
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<td>40.0</td>
<td>3.0</td>
<td>77.8</td>
<td>11.7</td>
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<td>30.0</td>
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<td>35.0</td>
<td>2.0</td>
<td>40.0</td>
<td>3.0</td>
<td>77.8</td>
<td>11.7</td>
<td>40.0</td>
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<tr>
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<td>6.0</td>
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<td>6.0</td>
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<td>9.5</td>
<td>40.0</td>
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<tr>
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<td>40.0</td>
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<td>7.5</td>
<td>45.0</td>
<td>14.0</td>
<td>60.0</td>
<td>5.0</td>
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<td>10.0</td>
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<td>100.0</td>
<td>6.0</td>
<td>120.0</td>
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<td>12.5</td>
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<td>75.0</td>
<td>25.0</td>
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<td>6.0</td>
<td>120.0</td>
<td>6.0</td>
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<td>12.5</td>
<td>75.0</td>
<td>25.0</td>
<td>120.0</td>
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<td>6.0</td>
<td>150.0</td>
<td>116.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**AMBULENT 100°F**
provides the derivation for all of the data shown in Table 3. The criteria for Table 3 and Appendix J are ambient temperatures of 100°F. Appendix K provides heat sink data and derivation for an ambient of 150°F controllers designed for operation. They require internal blowers to move heat across the heat sinks.

### 3.4 ADDITIONAL SALIENT TECHNICAL FEATURES OF THE MOTOR POWER CONTROLLER

Due to the nature and to the electronic design of the three-phase motor power controllers, they are a natural in terms of their ability to provide protection features for motors, under their control, not previously available. Conceivably, users could find value in the motor power controllers specifically for these features alone.

More and more motors are put on the line every year. This growing motor usage increases the risk of injury to plant personnel and increases the potential for greater downtime, higher motor costs, and fire damage caused by overheated and burned out motors.

Conditions leading to motor overheating and burnout fall into six (6) major categories:

A. Source induced:

   Phase failure, over and under current, phase sequence, and phase unbalance of incoming power decrease motor efficiency.
B. Load Induced:
Overload, jamming, underload, and long acceleration time raise or lower power demand from the motor, changing power used by the motor.

C. Application Induced:
High ON/OFF duty cycle, rapid reversing, and plug reversing cause repeated in-rush current levels that exceed full load current ratings, even though running current may be less than or equal to full-load current.

D. Load Wiring Induced:
Wire insulation failure and loose connections damage the controller which causes other problems, such as single-phasing, which damages the motor.

E. Motor Induced:
Insulation and bearing failures lead to excessive motor heating and burnout.

F. Environmentally Induced:
High ambient temperatures and contaminants increase motor temperature.

Motor protectors normally respond to one of two factors: (a) line current to the motor, or (b) motor temperature. Some protectors respond to both. For large motors (20 HP and up), current sensing is the preferred protection method. Most motor burnouts can be traced to excessive current surges.
The motor power controller uses current sensing as its primary mode of input data. Voltage sensing is done to derive the relationship to current. The controller electronics utilizes these two (2) parameters and generates some references of its own to complete the control process; therefore, the controller is a natural in terms of motor protection, since the controller monitors all three (3) current legs in a three-phase motor. Excessive current in any one phase can easily be detected. The controller monitors voltage in each leg, and therefore can detect a loss of phase. Also, low voltage can easily be determined.

IVECO Motor Power Controllers offer, as an option, a protection package that includes: Loss of Phase Detection, Low Voltage Threshold, and High Current Detection; any one of which will remove power to the motor. The controllers have been tested and can be equipped with added features, such as:

(a) Ramp start capabilities - This amounts to current limiting during start up, thereby minimizing excessive sudden energy requirements.

(b) Loss of phase protection - If power on one or two phases is lost, the controller can shut down the motor, thus protecting it from high torquing current on the remaining phases, possibly resulting in burnout.

(c) High current shutdown - Thermal shutdowns, a normal
feature of motors, are designed, not necessarily as motor protection, but rather to prevent fires. When a motor thermal cutout is activated, temperature is rising at an excessive rate and passes through the thermocouple activation point, i.e. it does not stop there. In other words, since temperature is still rising, further damage can occur to the motor even though thermal cutout occurs. The high current shutdown feature of the controller will protect the motor since detection is in milliseconds.

(d) Low voltage shutdown - During "brownouts", line voltage seriously drops and, in many cases, is low enough to cause heavy torquing and high current in the motor. Many motors are lost due to the thermal effects of this high current. The low voltage shutdown feature of the controller has the ability of pre-determining a minimum voltage of operation at which the motor is shut down. Actually, since the controller must turn triacs ON each one-half cycle, these triacs would not be turned ON if the line voltage dropped below the pre-determined value. Note that shutdown then, in the worst case, is no further away in time than approximately 8 milliseconds.

(e) Automatic recovery after shutdown - When all maligned parameters (above) return to normal, the controller automatically will restart the motor.
Figure 13 shows the circuit configuration for low-line voltage protection.

In the three-phase controller, the unregulated bus provides power to the oscillator buffer driving the triac gate-drive transformers. If the unregulated bus is not present, then no gate drive exists and the triacs are OFF, thus turning the motors OFF. The philosophy of the low-line protection circuit is to control the unregulated bus. When line voltage is above a pre-selected value, the op-amp provides a positive base voltage to an NPN switching transistor, thus permitting the unregulated bus circuit to pass. When the line voltage drops below the selected value, the op-amp output goes negative, thus turning the NPN transistor OFF. This, then, removes the unregulated bus from the triac gate drive, thus turning the triacs OFF, consequently shutting the motor down.

![Figure 13](image_url)

**Figure 13**
Low-Line Voltage Protection
The purpose of this circuit is to prevent a serious "brownout" from causing damage to motors which are under load, but starved for drive potential.

Figure 14 shows the loss of phase protection circuit configuration. Eventually, a signal from the three-phase voltages are brought to a three-input AND gate. The output provides positive base voltage to an NPN switching transistor, whereas before the unregulated bus current passes through the switching transistor. If any of the three-phase voltages is missing, the output of the AND gate goes to ground and base drive is removed from the switching transistor, causing removal of the unregulated bus to the triac gate drive buffers.

Figure 14
Loss of Phase Protection

As in the low-voltage protection philosophy, hi-current detection
is also based on a pre-selected threshold value, above which the controller removes power to the motor. Figure 15 shows the technique employed. Current is sensed in a power line, if it exceeds the pre-selected value, the unregulated voltage to the triac gate drives are removed, thus removing power to the motor.

![High Current Protection Circuit](image)

**Figure 15** High Current Protection Circuit

### 3.5 DIRECT BENEFITS

The direct benefit, as a result of using motor power controllers, include five (5) monetary saving items:

(a) Reduced direct energy costs - Savings are represented in power reduction directly off of the kilowatt meter.

(b) Demand charges reduced - Overall power is reduced appreciably during demand power periods.
(c) Reduction of poor power factor penalties - In induction motors, a reduction in load results in deterioration of power factor. The controllers are designed to maintain power factor at or near full load capacity values. Thus, during on-load periods, there is a significant improvement in power factor.

(d) Longer motor life - A reduction in operating temperatures extend the life of the motor. Typically, motor life doubles for every $10^0$ reduction in temperature.

(e) Lower air-conditioning costs - The industrial sites where there is a concentration of motors, a reduction in motor operating temperatures can reduce the thermal ambient. Typically, air-conditioning requirements can be reduced $0.25$ kilowatts for every one kilowatt reduction of power otherwise dissipated in heat.

3.6 THE MOTOR POWER CONTROLLER VERSUS CAPACITORS

Often-asked questions are: Can the controllers be used with capacitor banks? Do they replace capacitors? Should they not be used with capacitors?

Capacitors are often employed in shunt configurations to compensate for inductive loads. One must remember that placement of capacitors across a power line to compensate for an inductive load will compensate for one (1) specific value of inductive reactance. If a specific load has a fixed non-varying value of
inductive reactance, a capacitor of equal capacitive reactance can be placed across the power line, resulting in a power factor of 1.0. If a given load has a varying inductive reactance, no one value of capacitor can compensate for the varying inductive reactance, therefore the user must try to determine the average value of inductive reactance in order to decide on what capacitor value to employ. All motors represent inductive reactance on a power line. If the motor load varies, inductive reactance also varies. No value of fixed capacitance will compensate for the inductive reactance; therefore, a choice must be made regarding the value of capacitive reactance to be employed.

In industry, where many motors are used, capacitors are placed at the power line where power is metered to the facility. The large quantity of motors are usually in varying degrees of load, still others are ON, and others are OFF. An average value of inductive reactance can be determined at the meter and a capacitor bank used to compensate for the average. This is the method presently employed in industry so as to maintain a high power factor. The technique assumes that not all motors will be at their worst inductive reactance value at any given time, but that some will be high, some low, and there is a given range of average power factor for which the capacitors can compensate. On the other hand, if a motor load is constant, use of capacitors is a good approach, since they can compensate for the fixed value of inductive reactance. Conversely, if the motor load varies, ideally one would like to have capacitive
reactance vary inversely.

The motor power controller is designed to hold power factor at or near that which is present at full load, no matter what the loading or the load profile on the motor is. Note that the controller does not make any significant power factor improvement at full load; therefore, at full load some value of inductive reactance exists, but that value of inductive reactance, using the motor power controller, would remain at or near the full load inductive reactance value. One could, therefore, choose a value of capacitance which would provide a capacitive reactance to compensate for the motor inductive reactance at full load and permit the controller to provide constant power factor during the dynamic load profile. In this manner, the highest value of power factor can be maintained.

What about cases where capacitor banks are already used in industry at the substation or at the meter. If a controller is employed on motors within the facility, what must be done about the capacitor bank. Oftentimes, industry indicates that by use of capacitor banks at their meter or substation, they can maintain power factor as high as 0.9. Motor power controllers on individual motors could bring this value even higher. If the controller compensation were to cause the line to result in a capacitive power factor, it would be a simple matter of removing capacitors at the meter or substation.

The most important point to make about the capacitors versus the
motor power controller is that the motor power controller can make a very significant reduction in current flow through the motor; therefore, significantly reducing $I^2R$ losses. These losses result directly in heat.

In addition, the reduction of current through the motor also reduces $I^2R$ losses through all of the electrical wiring from the meter or substation to the motor.

The conclusion is that capacitors would not be done away with, but rather be used in conjunction with the controller so as to improve overall industrial power factor. Such improvements result directly in energy conservation and can reduce or eliminate power factor penalties where applied.

3.7 SUDDEN LOAD CHANGES

The attachments to the Work Statement included drawings as follows:

- Attachment 2 - Electronic Power Factor Controller Schematic For a Three-Phase Motor
- Attachment 3 - Drawing No. 50M25606 For a Single-Phase Motor
- Attachment 4 - Drawing No. 50M25607 For a Single-Phase Motor

Utilization of the circuitry shown in any of these schematics demonstrates that a sudden load, if heavy enough, can stall out the motor. A sudden load of any magnitude does cause a decrease in speed and motor torquing, causing a sudden rise in current which, if significant enough, and often enough, could cancel the savings during normal operation.
Figure 16 shows a circuit configuration which, when implemented into the control system electronics, will eliminate the previously described effects of a sudden load. This circuit is referred to as a "bump" load circuit. In effect, when a motor is subjected to a sudden load, the integrator op-amp, which normally would decrease in output voltage signal, is pulsed coupled to the "bump" load circuit which feeds back and inhibits a signal to the op-amp, thus driving the triacs full ON. When the "bump" load circuit recovers, the controller resumes normal operation.

3.8 NEUTRAL CONNECTION

In the field, there are often found two (2) types of three-phase motors. Those known as "delta" wound, and those known as "wye" wound. "Wye" wound motors have a neutral connection at the intercept of the three (3) legs of the "Y". In "Y" wound motors, the neutral connection is not readily available. Worse yet, such a connection would require that the controller be placed physically close to the motor. This is not necessarily desirable. One would prefer being able to locate the controller anywhere on the power line, preferably near a junction box or near the breakers.

The only real need for obtaining a neutral connection is to maintain phase sequencing and to assure proper time measurements between phases. The IVECO design is one that can be used on either "delta" or "wye"-wound motors and does not require a neutral connection. The neutral is internally derived, and phase relationships are thereby maintained. IVECO refers to
Figure 16 "Bump" Circuit for 1Ø & 3Ø Controllers
this technique as "phantom neutral", which is an IVECO proprietary design.

3.9 COST EFFECTIVENESS-AIR CONDITIONING

In applications such as the garment industry where a large number of motors are confined to a single area such as a large sewing room, the $I^2R$ generated in the motors accumulatively amounts to a significant heat source, which in the summertime, must be compensated for through the use of air conditioning. One can go through a rigorous calculation of the amount of heat in BTU that is generated, but such a calculation would be negated because of the large number of assumptions necessary. The best approximation to the cost effectiveness power factor control on these motors in terms of air conditioning reduction comes directly from the garment industry itself. A thumb rule often applied is the following: For every kilowatt of power reduced which is generated through $I^2R$ losses, one-quarter kilowatt of air conditioning can be eliminated. This thumb rule is employed in factories where more than 25 motors in any single area (room) are employed.

3.10 PAYOUT

What single factor would justify the use of the motor power controller by end users. A rule of thumb widely used in industry could be the guiding parameter in terms of an important single factor justification. "A capital investment is justified if that capital investment can be paid for by its dollar savings in two (2) years". The common term is "payout". This same
definition could also be applied to users of the power factor controller in residential applications. Payout is calculated as the sum of five factors.

The five factors are:

(a) Direct kilowatts saving as shown on the watt meter.
(b) Reduction in demand charges.
(c) Improvement in power factor at reduced loads.
(d) Motor longevity.
(e) Reduced air-conditioning requirements.

The savings resulting from direct kilowatts reduction is shown in equation 2:

\[
\text{Eq.2:} \ (\frac{\text{Hp}}{\text{Hp}}) \left( \frac{0.746\text{kW}}{\text{kWhr}} \right) \left( \frac{\text{hr}}{\text{yr}} \right) \left( \% \text{Savings} \right) \left( \frac{1}{\text{eff}} \right) = \$ / \text{yr. saved}
\]

The first two terms convert horsepower to kilowatts. The third term is the average electric utility rate. The fourth term is the number of hours the subject motor is operated in a year. The fifth term is the percentage savings, either expected or measured. The last term is the motor efficiency.

For purposes of estimating the effects of the other four factors, the following may be used:

(a) Savings in demand charges; add half again the savings calculated in equation 2.
(b) Savings in poor power factor penalties; add five percent of the savings calculated in equation 2.
(c) Savings due to air-conditioning reduction; add 25% of the savings calculated in equation 2.

(d) For motor longevity, assume an extension of 50%.

If the cost of the motor power controller is less than, or equal to, the payout required, then its use is justified. Note that payout is a function of horsepower and percentage savings where percentage savings itself is a function of the load profile. Load profile is defined as the mechanical loading (e.g., the electrical power demand) during one (1) complete cycle of motor load sequence.

3.11 LARGE-SCALE APPLICATIONS OF THE MOTOR POWER CONTROLLER

There are any number of large-scale applications for the motor power controller. Tests have been run on elevators, machine tools, pumps of various sorts, air-conditioners, etc. Any one of these applications could be classified as large-scale as defined by the NASA contract (i.e., 1,000 or more). Figure 8 of this report shows estimated motor population and electrical energy consumption by user category. This Figure is an excerpt from a U.S. Department of Energy Report No. DOE/TIC-11339. The Figure shows motor applications in various horsepower ranges by user category and SIC (Standard Industrial Code). The Figure shows, not only large-scale applications, but the number of hours per year of motor use. It is the combination of large-scale applications, as defined by NASA, and average use per year that is deemed important. Two thousand hours a year is typically a five-day, eight-hour week,
where 3,000 hours would be a twelve-hour day. Appendix E of this report shows Standard Industrial Codes applicable to Figure 8.

Large-scale applications can easily be seen in Figure 8 by observing the average use hours for any of the horsepower ranges. There are far too many to be singled out here. IVECO has, however, made tests using the motor power controller on applications such as air compressors, sewing machines, electric vehicle drive motors, plastic grinders, air handlers, elevators, vacuum pumps, air-conditioning blowers, and machine tools. Section 4.0 of this report encompasses test data, results of the tests, tests in progress, and future tests which will become a part of this report.

Appendix L is a derivation of potential energy savings for three-phase motors in the 1, 5, 20, 50, and 125 horsepower ranges, and by average annual use from 1,000 hours through 3,000 hours per year. Average estimated savings are also shown.

The data is derived from the potential energy conservation using the motor power controller of Table 2.

3.12 USE OF SCR'S

Development testing has shown that triacs cannot be used above 20 HP, 240V, three-phase and 30 HP, 480V, three-phase applications. The maximum extent of the electrical capability of triacs is met at these ranges. For motor power controllers operating with
motors larger than the above, SCR's as the switching element, must be used. From the standpoint of the control electronics, the only impact is assuring proper gate drive for the SCR's. The only other impact is the obvious mechanical method for thermal cooling.

3.13 COST/PRICE
Table 4 shows a typical price table for motor power controllers, both single and three-phase through 20 HP.

IVECO's philosophy, because of the extreme quantities of controllers required, is to market through distributors and dealers; therefore, the price table provides typical factory prices for a final selling price to which has been added distributor and dealer markups. Appendix M provides detailed cost-price breakdowns and "macro-material's" list.

All prices shown as based on quantities of 30,000 to 50,000 units.

(See following page for Table 4)
(This space purposely left blank)
### TYPICAL PRICE TABLE

#### 1φ, 120VAC, 60 Hz

<table>
<thead>
<tr>
<th>HP</th>
<th>Factory Price</th>
<th>Distributor</th>
<th>Dealer</th>
<th>Selling Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$51.62</td>
<td>20%</td>
<td>35%</td>
<td>$83.62</td>
</tr>
<tr>
<td>3</td>
<td>55.14</td>
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<td>89.33</td>
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<tr>
<td>5</td>
<td>58.65</td>
<td>20%</td>
<td>35%</td>
<td>95.00</td>
</tr>
</tbody>
</table>

#### 3φ, 240VAC, 60 Hz

<table>
<thead>
<tr>
<th>HP</th>
<th>Factory Price</th>
<th>Distributor</th>
<th>Dealer</th>
<th>Selling Price</th>
</tr>
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<tr>
<td>1</td>
<td>$120.80</td>
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<td>35%</td>
<td>$195.70</td>
</tr>
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<td>5</td>
<td>147.65</td>
<td>22.5%</td>
<td>40%</td>
<td>253.22</td>
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<td>10</td>
<td>173.10</td>
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<td>40%</td>
<td>296.87</td>
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<td>20</td>
<td>238.60</td>
<td>22.5%</td>
<td>40%</td>
<td>409.20</td>
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</table>

#### 3φ, 480VAC, 60 Hz

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<th>Dealer</th>
<th>Selling Price</th>
</tr>
</thead>
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</tr>
<tr>
<td>5</td>
<td>153.40</td>
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<td>40%</td>
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<td>10</td>
<td>180.30</td>
<td>22.5%</td>
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<td>20</td>
<td>251.10</td>
<td>22.5%</td>
<td>40%</td>
<td>430.64</td>
</tr>
</tbody>
</table>

### MARKETING PLANNING

In order to secure orders for the single and three-phase motor power controllers, a specific marketing strategy was established. The strategy was initiated and carried on simultaneously with the development program.
The motor power controllers (MPC) productwise, fall into the high quantity-medium price category, and as such, fit the mold for distribution methods of selling. This has the added advantage of maintaining smooth production cycles.

IVECO's marketing philosophy involves the establishment of up to ten (10) distribution centers located throughout the United States. Each center then employs up to 100 dealerships sized in accordance with the markets available in those areas.

IVECO believes that the motor power controller is an extremely important and valuable invention. The motor power controller potential is enormous and can eventually represent a very great energy savings. Care, however, must be taken to ensure that IVECO does not overextend itself in terms of trying to cover an excessively wide range of motor applications and markets.

3.14.1 Product Categorization

Motors employed in industry cover a very wide range of horsepower capability. It is obviously not practical from the monetary/payout standpoint to develop an all-encompassing controller. It would be price prohibitive to apply a motor power controller capable of operating at 20 HP to a motor application of 1 HP. Therefore, it is necessary to break down this wide range into a series of smaller horsepower ranges. The controller is then modeled to suit the smaller range categories. At the present time, several horsepower ranges are designated. Each range is covered by a separate version of the EY1021 or EY1027 series.
controllers as follows: The IVECO controllers are sized via two (2) basic motor parameters: (a) the motor horsepower, and (b) the motor voltage. The horsepower determines the triac size. The voltage determines the size of the input transformer.

**Single-phase Motor Voltage Controllers:**

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;A&quot; thru 1 HP</td>
<td>&quot;A&quot; 115 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;B&quot; thru 1½ HP</td>
<td>&quot;B&quot; 220 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;C&quot; thru 3 HP</td>
<td>&quot;C&quot; 115 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;D&quot; thru 5 HP</td>
<td>&quot;D&quot; 220 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;E&quot; thru 10 HP</td>
<td>&quot;E&quot; Custom, Specify</td>
</tr>
</tbody>
</table>

**Three-phase Motor Voltage Controllers:**

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;A&quot; thru 1 HP</td>
<td>&quot;A&quot; 115/200 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;B&quot; thru 3 HP</td>
<td>&quot;B&quot; 230/400 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;C&quot; thru 5 HP</td>
<td>&quot;C&quot; 460/800 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;D&quot; thru 7½ HP</td>
<td>&quot;D&quot; 115/200 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;E&quot; thru 10HP</td>
<td>&quot;E&quot; 230/400 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;F&quot; thru 15HP</td>
<td>&quot;F&quot; 460/800 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;G&quot; thru 20HP</td>
<td>&quot;G&quot; Custom, Specify</td>
</tr>
<tr>
<td>&quot;H&quot; thru 30HP</td>
<td>&quot;H&quot; 115/200 VAC, 60 Hz</td>
</tr>
<tr>
<td>&quot;I&quot; thru 50HP</td>
<td>&quot;I&quot; 230/400 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;J&quot; thru 80HP</td>
<td>&quot;J&quot; 460/800 VAC, 50 Hz</td>
</tr>
<tr>
<td>&quot;K&quot; thru 100HP</td>
<td>&quot;K&quot; Custom, Specify</td>
</tr>
</tbody>
</table>

IVECO INC.
IMPROVEMENT VIA ELECTRONICS
3.14.2 **Strategy**

The basis for this marketing plan assumes a two-step distribution system on a national basis.

The United States is divided into seven (7) major markets. Each of these markets are given a priority target value which establishes their order of importance and scheduling for penetration. It is critical that flexibility be maintained regarding these targets so that reaction to changing market conditions be quick and concise, if necessary. Penetration into each marketing area is governed by total production capability.

Seven (7) Key Market areas have been established and are shown in Figure 17; they include:

1. West
2. Northeast
3. Southeast
4. North Central
5. Central
6. South
7. Metro - East

Headquarter cities for the Key Market Areas are:

<table>
<thead>
<tr>
<th>Region</th>
<th>Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>Los Angeles - San Francisco</td>
</tr>
<tr>
<td>North East</td>
<td>Hartford - Boston</td>
</tr>
<tr>
<td>South East</td>
<td>Atlanta - Miami</td>
</tr>
<tr>
<td>North Central</td>
<td>Chicago</td>
</tr>
<tr>
<td>Central</td>
<td>Kansas City - St. Louis</td>
</tr>
<tr>
<td>South</td>
<td>New Orleans - Nashville - Dallas</td>
</tr>
<tr>
<td>Metro - East</td>
<td>New York - Philadelphia</td>
</tr>
</tbody>
</table>
These are suggested only and when desirable qualified distributors are available. It is possible that their headquarter cities may differ with the suggested location. Obviously, an adjustment would be made.

Table 5 provides a listing of areas by states.

<table>
<thead>
<tr>
<th>MARKET AREA</th>
<th>AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>Washington, Oregon, Idaho, Montana, Wyoming, California, Nevada, Utah, Colorado, Arizona, New Mexico, Alaska, Hawaii</td>
</tr>
<tr>
<td>North East</td>
<td>Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island</td>
</tr>
<tr>
<td>South East</td>
<td>West Virginia, North Carolina, Virginia, South Carolina, Georgia, Florida, Maryland, Delaware, Washington, D.C.</td>
</tr>
<tr>
<td>North Central</td>
<td>Michigan, Wisconsin, Illinois, Indiana, Ohio</td>
</tr>
<tr>
<td>Central</td>
<td>North Dakota, Minnesota, South Dakota, Iowa, Nebraska, Kansas, Missouri, Oklahoma</td>
</tr>
<tr>
<td>South</td>
<td>Texas, Kentucky, Tennessee, Arkansas, Louisiana, Mississippi, Alabama</td>
</tr>
<tr>
<td>Metro - East</td>
<td>New York, New Jersey, Pennsylvania</td>
</tr>
</tbody>
</table>
Two-step distribution demands a close working relationship between the factory and distributors and on a periodic basis, certain dealers for the company. The company attitude is always: "sell through" and not "sell to".

Product problems if any, including pricing, and application of product is an open line of communication between Factory - Distributor - Dealer.

Marketing education techniques are vital to any "Sell Through" program. IVECO's responsibility to the distributor - dealer organization ends only when the product is sold.

Product benefits must be incorporated into a major thrust at the Dealer level. Working through distributors, it must be made certain that IVECO's story is properly and frequently told. Dealer training must become IVECO's responsibility until it is certain that the distribution pattern is established on a market basis, and is fully qualified to handle all aspects of our marketing needs.

Starting in the West is highly logical since freight problems, logistics, marketing help, and assistance are surely easier to handle without high travel costs and/or on a long distance basis. California - properly handled, could well take most of the first years production and provide some first-hand knowledge of potential problem areas, as well as opportunities. A well-controlled and orderly growth pattern from that beginning
is highly advisable, and with proper targeting will assure success.

The goal in the West is the complete marketing of the eleven (11) Western states.

3.14.3 Distributor Profile

Before enlisting a distributor organization, it is necessary that his philosophies, methods and ethics be consistent with the Factory. The following describes the IVECO distributor profile:

(a) Proven ability to take new and/or innovative product to market.

(b) Warehouse or stocking capability.

(c) Sales force calling on stratified dealer structure.

(d) Strong financial capability.

(e) Ability to lead - direct sales force to major industrial and commercial users.

(f) Willingness to "go direct" if necessary to insure companies market share.

(g) Continuity in market place - or track record if a new operation.

3.14.4 Product Warranty

A clear, concise, written warranty, spelling out any limitations is essential.
3.14.5 Packaging

Packing and shipping procedures should be reviewed periodically to be certain that we are meeting the needs of the customer.

3.14.6 Advertising

Initial start-up advertising plans at the distributor level should be reviewed by the factory until appropriate guide lines are agreed upon. Overstating our products capability, or misleading anyone, however unintentional, must be avoided.

3.14.7 Distributor Contracts

Distributor Contracts should be clearly written and spelled out in understandable terms, describing the responsibilities of the distributor as well as the manufacturer.

IVECO assumes the manufacturer's position at all times. The fact that the product is contracted for assembly has no bearing on the IVECO - Distributor relationship. It is not likely that all distributors have the same distribution background or marketing approach. With that in mind, IVECO's strategy, with certain distributors, may have to vary with their marketing approach and expertise. Once established, and once IVECO has identified distribution needs in the market place, then IVECO can guide distribution to new markets and opportunities.

Distributors must be assigned specific quotas and measured on a timely basis as to attaining established goals.
4.0 TEST DATA/REPORTS

During the course of this contract, many technical problems were encountered in the field. The technology of the motor power controllers can be considered new and, as a result, many implications of their application were unknown prior to use. It was found that many motors, in their present operating applications, can be classified as unstable.

The electronic nature of the controller versus the electrical nature of the motor, compounded this problem due to the differences in response time of the two devices. Application for test data collection was hampered by technical anomalies encountered during the test period of this contract. For this reason, two time extensions were sought and granted. Up to the final month of the contract period, some instability was still being seen in the field, consequently, not all tests have been completed to the satisfaction of IVECO. Such tests will be completed at IVECO's expense and will be submitted as an addendum to this report.

Table 6 provides a summary of the results of tests successfully completed. Most of the tests indicate greater savings than was anticipated. The only explanation for some of the surprising results is that theoretically all of the $I^2R$ loss savings were not anticipated. Also, there is an effect on efficiency which has not been included in the calculation.
The following is a list and description of tests yet to be completed and will be provided in the aforementioned addendum:

(A) Sandia Labs, Albuquerque, New Mexico
   (1) Vacuum Pump, 3 HP, 240VAC
   (2) Lathe, 10 HP, 480VAC, 3Ø

(B) Southern California Edison
San Bernardino, California
   (1) Air Conditioner Fan
   10 HP, 480VAC, 3Ø

(C) Washington Metro Rapid Transit Authority
Washington, D.C.
   (1) Escalator,
   10 HP, 480VAC, 3Ø

(D) Goodrich (Martha Mills)
Griffin, Georgia
   (1) Twister
   15 HP, 480VAC, 3Ø

(E) SPEC Tool Company
Pico Rivera, California
   (1) Air Compressor
   25 HP, 480VAC, 3Ø
# TABLE 6

## MOTOR POWER CONTROLLER ENERGY SAVINGS

### THREE-PHASE AC INDUCTION MOTORS

<table>
<thead>
<tr>
<th>ITEM</th>
<th>USER</th>
<th>MOTOR DESCRIp.</th>
<th>O/P SAVED</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SANTA ANA COUNTY, CA</td>
<td>10 HP, 480VAC, 3φ</td>
<td>16%</td>
<td>Air Compressor</td>
</tr>
<tr>
<td>2</td>
<td>PIERCE COLLEGE</td>
<td>Pasadena, CA</td>
<td>5 HP, 230VAC, 3φ</td>
<td>43%</td>
</tr>
<tr>
<td>3</td>
<td>NEWELL PLASTICS</td>
<td>Glendale, CA</td>
<td>3 HP, 230VAC, 3φ</td>
<td>40%</td>
</tr>
<tr>
<td>4</td>
<td>DISNEYLAND</td>
<td>Anaheim, CA</td>
<td>3 HP, 480VAC, 3φ</td>
<td>44% Uphill</td>
</tr>
<tr>
<td>5</td>
<td>BLUE BELL</td>
<td>Atlanta, GA</td>
<td>½ HP, 208VAC, 3φ</td>
<td>30% Avg.</td>
</tr>
<tr>
<td>6</td>
<td>DIXIE YARN</td>
<td>Atlanta, GA</td>
<td>½ HP, 208VAC, 3φ</td>
<td>31% Avg.</td>
</tr>
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</table>

### SINGLE-PHASE AC INDUCTION MOTORS

<table>
<thead>
<tr>
<th>ITEM</th>
<th>USER</th>
<th>MOTOR DESCRIp.</th>
<th>O/P SAVED</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HOME APPLIANCE</td>
<td>½ HP, 115VAC, 1φ</td>
<td>35%</td>
<td>Evaporative Cooler</td>
</tr>
<tr>
<td>2</td>
<td>HOME APPLIANCE</td>
<td>½ HP, 115VAC, 1φ</td>
<td>16.5%</td>
<td>Central Heating Blower Fan</td>
</tr>
<tr>
<td>3</td>
<td>DISNEYLAND</td>
<td>Anaheim, CA</td>
<td>½ HP, 230VAC, 1φ</td>
<td>41%</td>
</tr>
<tr>
<td>4</td>
<td>SANDIA LABS</td>
<td>Albuquerque, N.M.</td>
<td>115VAC &amp; 230VAC, 1φ</td>
<td>25%</td>
</tr>
</tbody>
</table>
APPENDIX A
STATEMENT OF WORK

A. Technical Requirements:

1. Perform engineering development on the existing circuitry for both single and three-phase motors and recommend modifications which will improve the performance, producibility, and/or applicability of the circuit (e.g., investigate a method of eliminating the need to bring out the neutral of a wye-connected three-phase motor). These modifications will be implemented upon approval of the COR.

2. Determine the ability of the circuit and motor to respond to sudden changes in loading. If it is determined that a given type of loading results in instabilities, recommendations shall be made for modification which eliminates the problem. These modifications will be made upon approval of the COR.

3. Study various types of motor applications and identify those applications where this controller would be beneficial.

4. Identify and/or define a large scale application (i.e., 1,000 or more) of motors with a cyclic load and determine the cost effectiveness of applying the motor controller. This shall be done for both a single-phase application and a three-phase application.

5. Study and provide a discussion concerning the potential this controller has for reducing the costs that users of motors presently pay for having a poor power factor or for IVECO INC.
IMPROVEMENT VIA ELECTRONICS
uneconomical electrical demand.

6. Study the potential this controller might have for minimizing the need for power factor correction capacitors or synchronous motors in a typical application. If it is found that the potential exists, take the example in paragraph "4" above and determine by analysis the benefits.

7. Study and provide a discussion on whether the cost effectiveness of this controller can be enhanced in certain applications by serving also as the power contactor for the motor.

8. Study and provide a discussion on whether the cost effectiveness of the controller (with modifications) can be enhanced by serving as an inrush current limiter in larger motors.

9. Cost effectiveness studies shall take into consideration the reduction in air conditioning load through reduction in heat generated by the electric motors.

10. High density packaging is not required. A packaging volume for the single-phase controller of 35-40 cubic inches (approx. 6" x 4" x 1\(\frac{1}{2}\)") and 50-60 cubic inches for the three-phase controller will be acceptable.

11. Provide a cost estimate for 1 H.P. single-phase motor controllers based on production rates of 10,000, 20,000, and 30,000 units per month. Repeat this cost estimate for 3 H.P. three-phase controllers. The contractor shall estimate the cost variance with motor horsepower for the two types of controllers.
12. The contractor shall have the capability to manufacture 30,000 controllers per month.

13. Deliverable end items under the terms of this contract shall be 18 packaged single-phase controllers, which accommodate up to 5 horsepower and 240 volts, and 6 packaged three-phase controllers, which accommodate up to 10 horsepower and 440 volts, plus the written discussions and reports called for.

14. The first two single-phase controllers and the first two three-phase controllers complete will be furnished to MSFC.

15. Details of the circuitry are given in the attachment to the statement of work. (Attachment 1)

16. After completion of this contract effort, the disposition of the 10 controllers will be at the discretion of the prime contractor.

B. General Requirements:

1. The contractor will select seven (7) separate industrial or public sector organizations that will agree to have these controllers installed and tested for a period of time deemed necessary to demonstrate the effectiveness of the controller. Three (3) of these selected sites will have controller installed on single-phase motors, and the other four (4) sites will have the controller installed on three-phase motors. One single site may be utilized for testing both type controllers.

2. The contractor shall provide the engineering services required to install, monitor, and maintain the controllers.
at all sites, and to collect and record the appropriate operational

test data.

3. The contractor shall propose to NASA a cost-sharing

plan which will clearly define all resources the contractor

proposes to contribute to this effort. This plan is required in

order to determine the desire and interest of the contractor in

commercialization of this Power Factor Controller.

4. The contractor shall provide a marketing/commerciali-

zation plan.

5. User safety shall be considered in the design and

packaging of the units.

NOTE: The following attachments are furnished for information

only:

Attachment 2 - Electronic Power Factor Controller Schematic

for a Three Phase Motor

Attachment 3 - Drawing Number 50M25606 for a Single Phase

Motor

Attachment 4 - Drawing Number 50M25607 for a Single Phase

Motor
APPENDIX B
REPORTS

A. Progress Report

During the period of this contract, the contractor shall submit a monthly progress report. This report shall be postmarked on or before the 19th of the month succeeding the period. This report shall be of brief narrative letter type and shall include the following:

1. A brief quantitative description of the work performed during the period and a discussion of the work to be performed during the next reporting period.

2. A discussion of any current problems which may impede performance, impact program schedule, and cost. Indicate what corrective action is being taken.

3. In addition, the following shall be furnished:
   a. Total cumulative costs incurred as of the report date.
   b. Estimate of cost to complete contract.
   c. Estimated percentage of physical completion of contract.
   d. Statement relating the cumulative costs to the percentage of physical completion with explanation of any significant variance.

B. Final Report

The contractor shall submit a final report which documents and summarizes the results of the entire contract work, including
recommendations and conclusions based on the experience and results obtained. The final report shall include, as applicable, tables, graphs, diagrams, sketches, curves, procedures, photographs, test data and drawings in sufficient detail to comprehensively explain the results achieved under the contract. The contractor shall submit two (2) draft copies of this report to the Contracting Officer's Representative (COR) for approval prior to final printing and distribution. The report will contain all site test data for the packaged single-phase and three-phase controllers and include type of motors used in test demonstration activity.

C. Reports Distribution

Copies of reports, other than those with specific addresses, shall be distributed to National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812, to the codes and in the quantities indicated below. A copy of the transmittal letter showing distribution of the reports shall be furnished to AP28H.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Monthly</th>
<th>Final Draft</th>
<th>Final Approved</th>
<th>pDrawings &amp; Specifications</th>
</tr>
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<tbody>
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<tr>
<td>NASA Headquarters/Washington</td>
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<td></td>
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<tr>
<td>ETU-6/L. Mogavero</td>
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<td>0</td>
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IVECO INC.
IMPROVEMENT VIA ELECTRONICS
APPENDIX C

UL TECHNICAL SUBMITTAL
TECHNICAL DESCRIPTION

MODEL EY 1021

MOTOR POWER CONTROLLER
(SINGLE PHASE)

IVECO, INC.
5762 Research Dr.
Huntington Beach, CA.
92649
(714) 891-9922
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II  GENERAL DESCRIPTION

III  DETAIL TECHNICAL DESCRIPTION

IV  MODEL EY1021 HARDWARE REVISION

## Appendix

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
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</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>001</td>
<td>Power VS Load Curve.</td>
</tr>
<tr>
<td>002</td>
<td>General Block Diagram Model EY1021 Motor Power Controller.</td>
</tr>
<tr>
<td>003</td>
<td>Electrical Block Diagram Model EY1021 Motor Power Controller.</td>
</tr>
<tr>
<td>004</td>
<td>Timing Diagram.</td>
</tr>
<tr>
<td>005 A &amp; B</td>
<td>Electrical Schematic Model EY1021 Motor Power Controller.</td>
</tr>
<tr>
<td>006</td>
<td>Electrical Schematic Model EY1021 Motor Power Controller revised.</td>
</tr>
</tbody>
</table>
INTRODUCTION

The purpose of the Motor Power Controller (also known as Power Factor Controller) is to improve power factor and reduce power dissipation in induction motors operating below full load. The Motor Power Controller is capable of raising power factors from 0.2 to 0.8 and results in energy savings as shown in figure 001.
II GENERAL DESCRIPTION (Refer to figure 002).

Power losses are reduced by sensing the phase lag between the motor voltage and current. This information is fed to the electronic controller which forces the motor to run at a constant predetermined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (i.e. triac or the equivalent) which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac remains ON until the current goes through zero. Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to the motor, the gate is triggered at a given point during the cycle, and the device switches OFF as the current goes through zero.
III DETAIL TECHNICAL DESCRIPTION

The reactive volt-amps of an induction motor is high when the motor is unloaded or partially loaded. Some motors tested showed unloaded current to be about 90 percent of the rated load current. These currents cause heat losses in the motor.

Since the current remains high in an unloaded motor, the phase between the voltage and current shifts with load. Typically, the current may lag the voltage 80 degrees in an unloaded motor and 30 degrees when loaded. Figure 003 shows how the power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference between the two produces an error signal which biases a ramp voltage that is in sync with the 60 hertz line voltage. The intersection of the ramp and the error voltages is detected by a squaring amplifier whose output provides the time for turning-ON a triac (or SCR's) in the motor line.

Thus, the ON time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are shown in the timing diagram of figure 004.
III  DETAIL TECHNICAL DESCRIPTION (con't)

The phase angle shown as \( \theta \) in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

When the circuit is in control of the motor current, voltage is applied to the motor for a portion of each positive and each negative half cycle of line voltage by means of the solid-state switch (triac) as seen in the timing diagram.

When the triac switches ON, rapid rise of the current is prohibited by the inductance of the windings. The current rises, reaches a peak, and then follows the voltage down as it approaches zero, but with a finite lag. Although the firing voltage to the triac goes to zero when the line voltage goes through zero, the triac inherently will remain ON until the current goes through zero. This is shown by the motor voltage waveform.

The phase lag between voltage and current is indicated by \( \theta \) in the timing diagram. This is the parameter which is to be measured and controlled. The line voltage and its inverse are squared by squaring amplifiers as indicated by \( E \) and \( \overline{E} \) in the timing diagram. Each current pulse is squared by similar amplifiers as indicated by \( I \) and \( I' \). By "AND'ing" \( \overline{E} \) with \( I \), and \( E \) with \( I' \) and then "OR'ing"
III  DETAIL TECHNICAL DESCRIPTION (con't)

the two, a pulse train is produced which has a pulse width proportional to the phase angle between voltage and current. When acted on by a low pass filter, the dc or average value of this voltage will be proportional to the phase angle. This voltage is summed with a command voltage from P1 (Electrical Block Diagram) which is indicative of a desired phase angle. The difference of the two is the system error voltage. This error is compared with a ramp which is synchronized with the zero crossings of the line voltage. The intersection of the sloped portion of the ramp and the error voltage are detected by the comparator Q2 and form the turn ON pulse for the triac.

As the load on the motor is decreased, the slight change in phase angle causes the error to drop and intersect the ramp at a lower point. This moves the firing pulse to the right, along the sine-wave, causing the triac to turn ON for a shorter duration, lowering the applied voltage. Conversely, an increase in load will cause the firing angle to move to the left and apply more voltage to the motor. Thus, a phase angle is commanded and the high gain of the feedback loop will vary the applied voltage to force the motor to operate at the desired phase angle regardless of load. Since the current is never higher than that required for a given load, motor losses are minimized.
III DETAIL TECHNICAL DESCRIPTION (con't)

A detailed electrical schematic of the EY1021 Motor Power Controller is shown in figure 005. Resistor R 8 and capacitor C 4 are used to reduce the EMI and RFI effects of the triac (or SCR) switching.

The difference in unit make-up for various horsepower involves changing triacs to accommodate larger current values and apply outside heat sinks for three-horsepower (and up) 115 VAC units as well as five-horsepower (and up) 120 VAC units. A chart showing triac VS horsepower is provided in Appendix B.

Appendix C is a copy of the patent covering the Power Factor Controller (Patent Number 4,052,648).
IV  MODEL BY1021 HARDWARE REVISION

IVECO intends to modify the single phase Motor Power Controller by replacing the printed circuit board and eliminating the transformer. The existing hardware is in accordance with the schematic shown in figure 005 A & B and Parts list number PL 1021-006-00038A. The revised hardware is in accordance with the schematic shown in figure 006 and Parts list number PL 1021-006-00061A. There are no other changes to the hardware; i.e. triac and heatsink selection are per appendicies B and E respectively.

The units function identically except that the revised hardware has an added feature referred to as a "bump" circuit. The bump-circuit is made up of C 7, R 18, 19, 20, CR 9, and U2D. This circuit provides instant response to suddenly increasing or clutched-in loads.
Power vs. Load Curve

Figure 001

POWER WITHOUT CONTROL

SAVINGS

POWER WITH CONTROL
GENERAL BLOCK DIAGRAM

Figure 002

Notes:
- Refer to Hook-Up Instructions.

Line Voltage 50/60 Hz

Model E1021 Motor Power Controller

IVERO INC
ELECTRICAL BLOCK DIAGRAM
MODEL FY1021
MOBIL 602: CONTROLLER

FIGURE 003

IVECO INC
OPERATIONAL CHARACTERISTICS OF 1Ø UNIT

P/N EY1021

The voltage sense comparator output and the current sense comparator are square waves of opposite polarity with the voltage leading by 30 degrees to 45 degrees (This depends on the power factor, i.e. inductance of the motor. If the power factor is 1.0 it would be exactly 30 degrees). On a dual channel scope this will appear as:

\[ E_s \quad \downarrow \quad \phi \approx 30^\circ \]

\[ I_s \]

The output of the integrator is a varying DC level from +7v to -7v. The level is determined by two factors,
1) The current leading angle (i.e. Motor Power Factor).
2) The setting of the adjustment control. With the pot full CW the output will be full positive and the triac driven full ON. When the output goes below GND the triac will be turned OFF.

The signal will appear as:

\[ + \quad \downarrow \quad 0 \]

The output of the ramp generator is in sync with the voltage sense square wave. The negative edge creates one ramp, the positive edge creates another thus there is one for each cycle of the line voltage sine wave. The signal will appear as follows compared to the voltage sense:
The output of the summing amp (Q3 & Q4) also provide the triacs gate drive current. A positive signal is required to turn ON the triac. With the adjustment control full CW (i.e. no control) the collector of Q4 will be at +7v. With the unit controlling the signal will appear as:

When the signal goes low the triac is turned OFF.

The voltage signals across the motor, triac and current sense is shown with respect to each other and the unit controlling with a retard angle of 30 degrees.
SCHEMATIC

CONTROLLER ELECTRONICS

P/N EY1021

Figure 005A
APPENDIX A

MOTOR POWER CONTROLLER
SINGLE PHASE
MODEL EY1021

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**ORIGINAL PAGE 13**
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**THAILAND**
NOTES

1 TR1 is TECO LYD0E3 or TEZ ACOVB3 (120VAC), ACOVB3M (240VAC).
2 Enclosure: Use DD-0014 for NEMA 1 or DD-0015 for NEMA 3E.
3 Heatsink: Refer to DD-0013 for heatsink selection.
4 Refer to DD-0016 for wire size selection.

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IVECO

IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

MOTOR POWER CONTROLLER
MODEL 8Y1021

DEVELOPMENT

PL 1021-006-0006A1
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APPENDIX B

TRIAC SELECTION
SINGLE PHASE MPC
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<tr>
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<th>V(MOT)</th>
<th>PD</th>
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<td>400</td>
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NOTES:
1. Refer to IVECO DD-0013 for Heat Sink A
   Refer to IVECO DD-0013 for Heat Sink B
   Refer to IVECO DD-0013 for Heat Sink C
2. Calculations based on:
   \[ I_{FLA} = \frac{(746) HP}{V(MOT)(off+pf)} \]
   where: \( (off+pf) \approx 0.75 \)
3. All triacs are isolated types.
### Definitions

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<td>HP</td>
<td>Horsepower</td>
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<tr>
<td>FLA</td>
<td>Full Load Amps (associated with motors)</td>
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<tr>
<td>V(mot)</td>
<td>Motor Voltage (line)</td>
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<tr>
<td>PD</td>
<td>Power Dissipation in triac element (or SCR) inlet</td>
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<tr>
<td>I_t</td>
<td>Triac steady-state current maximum</td>
</tr>
<tr>
<td>V_{dem}</td>
<td>Triac OFF-state maximum voltage</td>
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<tr>
<td>HS</td>
<td>Heat Sink</td>
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**SINGLE PHASE MTC**

**TRIAC SELECTION**
APPENDIX C

U.S. PATENT 5,052,648

POWER FACTOR CONTROL SYSTEM
FOR AC INDUCTION MOTORS
A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement. Power is thus provided to the motor at its most efficient point.
POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention
This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art
The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Heretofore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal 115-volt service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention
It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will effect a reduction in power normally provided by the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical schematic diagram of an embodiment of the invention.

FIGS. 2a-2f are waveforms illustrating aspects of operation of the invention.

FIG. 3 is a plot illustrating power drawn by a motor for different states of loading and with and without the control system of this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An AC induction motor 10 is powered by an alternating current voltage 12 (FIG. 2a) through switch 14 and connectible at terminals 16. The switched AC power is also applied to transformer 18 and circuit bias power supply 20. Triac 22 is connected in series with motor 10 and is triggered for controlled portions of each half cycle of power input. A small value resistor 24 of 0.010 to 0.020 ohms is connected in series with motor 10 and serves to develop a signal 26 (FIG. 2b) which is proportional to the current flow through the motor. FIG. 2b illustrates an instantaneous state of operation after initial start-up and with an initial optimum input voltage-load relationship, whereby triac 22 is fully on and load, thereafter, loading is substantially decreased. The initial current-voltage phase lag 28 for such optimum state of operation may vary from motor to motor and would be determined for each motor with which this invention is to be employed. In the present example, initially, optimum phase lag 28 is approximately 30°, and potentiometer 78 is adjusted to provide the zero error output signal for the control of the turn on time of triac 22 to maintain the phase angle of this or another selected value. The occurrence of increased current lag 28a at time T, depicts a sudden decrease in loading of motor 10. The detection of this is used, as will be further explained, to reduce the average amplitude of input voltage and thereby to effect a commanded, optimum, phase lag.

To further examine the circuitry, transformer 18, having center tap secondary 32, provides oppositely phased inputs to square wave shapers 34 and 36, and the resulting oppositely phased outputs, square wave 38 (from shaper 36) shown in FIG. 2c and square wave 40 (from shaper 34) shown in FIG. 2d, which are fed to saw tooth or ramp wave shapers 42 and 44, respectively. The outputs of the wave shapers are combined to provide a ramp wave each half cycle of the alternating current input as shown in waveform 46 (FIG. 2e). Waveform 38 is also used as a reference signal for the phase of input voltage and is fed to one input of multiplier 48, functioning as a phase detector, to which is also fed a current reference signal 50 shown in FIG. 2f. The current reference signal is generated as follows. Current signal 26 (FIG. 2b) from resistor 24 is fed to isolation transformer 52 and from it to square wave pulse shaper 54, which provides square wave 56 (FIG. 2e). This square wave is differentiated in differentiator 58 to provide positive impulses 60 shown in FIG. 2g and the negative impulses (derived from the trailing edge of square wave 56) are used to trigger one-shot 62, which provides as an output the square waveform 50 shown in FIG. 2g. This square waveform commences at a time corresponding to the trailing or zero crossing point of current signal 26 (FIG. 2b) and has a duration determined by the time constant of one-shot 62 corresponding to the length of a half cycle of AC input to the motor. Thus, there is generated a square wave current signal which is of the
5 Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:
   - current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;
   - voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;
   - phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and
   - said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

5. A control system as set forth in claim 1 wherein:
   - said current sampling means includes means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and
   - said voltage sampling means comprises means for providing a signal proportional to the voltage across said resistor.

4. A control system as set forth in claim 3 wherein:
   - said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

2. A control system as set forth in claim 1 wherein:
   - said current sampling means includes a resistor adapter to be placed in series with a said winding and means for providing a signal proportional to the voltage across said resistor.

4. A control system as set forth in claim 2 wherein:
   - said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and
   - said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

5. A control system as set forth in claim 4 wherein:
   - said control means includes:
   - pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and
   - switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.

  * * * * *
APPENDIX D

SET-UP INSTRUCTIONS

MODEL EY1021 MPC
The following is a procedure for adjustment and "peaking" the ET1021 Motor Power Controller. To achieve adjustment for maximum power savings, the motor should be at no-load or at some constant load less than full load. **DO NOT** try to make adjustment when the motor is under varying load. A light load on the motor is recommended.

**Apparatus/Tools Required**
1. A small Screwdriver
2. A clamp-on Ammeter

**Step 1.** Locate "Phase-Angle Adjust" potentiometer; See figure 1.
**Step 2.** Turn "phase-angle adjust" pot **clockwise** for 10 full turns.
**Step 3.** With power-OFF, attach the motor power controller as shown in the attached drawing No. 1021-012-000002, entitled "Electrical Interface".
**Step 4.** Start motor/controller system and allow five minutes warm-up before continuing.
**Step 5.** Using the clamp-on ammeter measure the current in motor lead No. 2; note current. See figure 2.
**Step 6.** While observing the ammeter, turn phase-angle adjust pot **clockwise**; there should be no change in metered current. If current does increase, continue turning the adjustment potentiometer clockwise until no current change can be seen.
**Step 7.** Slowly turn "phase-angle adjust" potentiometer **counterclockwise** until motor current, as shown on the meter, begins to decrease.
**Step 8.** Continue turning the potentiometer **counterclockwise** very slowly while watching the meter. When the motor current levels off and shows a slight increase---STOP immediately and reverse the adjustment direction so as to bring the current back slightly. **THE ADJUSTMENT IS COMPLETE.**

**NOTE:** If, in following this procedure, no dip in current is noticed (apparent using some motors) set the controller for the lowest possible position at which the motor responds to load change increases without stall.

---

**IMECO**
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647
(714) 842 - 2925
MODEL EY/1021
ELECTRICAL INTERFACE

NYC ELECTRONICS
318 East
Huntington Beach, CA 92647

1021-012-00002 A
APPENDIX E

HEATSINK SELECTION
SINGLE PHASE MPC

MODEL EY1021
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Notes: Replacement for B; refer to IVECO Dec # 1021-010-00060A.

ORIGINAL PAGE 13
OF POOR QUALITY
NOTES:
1. MAKE FROM 1 3/4" x 1 3/4" x 1/8"
   STANDARD 6063-T5 ALUMINUM EXTENSION.

\[ \text{\textcopyright 1980 \textregistered} \]
NOTES:
1. MAKE FROM 1\1/4" x 1\1/4" x 1\8"
   STANDARD 6063-T5 ALUMINUM
   EXTRUSION.

IVECO INC
5762 RESEARCH DR.
HUNTINGTON BEACH CA 92649

TITLE: BRACKET
SINGLE-PHASE HEATSINK
STUD-MOUNTED TRIAC

DRAWN: 1021-010-00029A REV A
1. Use Aavid Pin 60885, or equivalent, in 4 inch lengths
2. 9.5 x 8 1/16", 0.516/14", 5.29/4" / 3"
Notes:
1. Use AAGUID P/N 60685 or equivalent, in 4 in lengths
2. 9.5 sq in/2", 0.5 1/2", 5.20/4 1/2"

1UECO INC
5762 Research Dr.
Huntington Beach CA
92647

11/4/90
EXTERIAL HEATSINK
SINGLE-PHASE MFC
STUD MOUNT

Scale 1/1
1021-010-00041A A
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</table>

### Notes
1. WEI Corp P/N 3160 or equiv
2. Cut in 3.00 inch lengths
3. 1 HS per unit
4. \( \frac{1}{4} \) inch hole in center for trapezoidal mount

---

**WEI Corp**
1405 S Village Way
Santa Ana, CA 92705
(714) 831-9333

---

**VETO INC**
5762 Research Dr
Huntington Beach, CA 92649

3½ HP HEAT SINK 1Ø MFC
MODEL EV1021

**DPC #1021-010-000000A**
APPENDIX D

POWER FACTOR CONTROL SYSTEM

FOR AC INDUCTION MOTORS

US PATENT NO. 4,052,648

IVECO LICENSE NO. 477
Save Power In AC Induction Motors

Electronic control loop conserves energy by reducing the voltage applied to lightly loaded motor.

Relatively simple and inexpensive circuitry will improve the power factor and reduce power dissipation in induction motors operating below full load. Power factors as low as 0.1 or 0.2 can exist when such motors are partially loaded or unloaded. When this is the case, relatively large currents flow, and little work is being performed. Hence, 1/ZR losses will occur at all points in the distribution system, including the motor windings, even though no mechanical power is delivered.

An electronic control system has proved, under tests, capable of raising power factors from 0.2 to 0.8 and resulting in energy savings as shown in Figure 1. The power losses are reduced by sensing the phase lag between the voltage and current. This information is fed to the electronic controller shown in Figure 2. This circuit forces the motor to run at a constant predetermined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (such as a Triac or equivalent), which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the Triac remains on until the current goes through zero. Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to a motor, the gate is triggered at a given point during the cycle, and the device switches off as the current goes through zero.

The circuitry in the top half of Figure 2 is a typical phase-control and firing-angle circuit. Voltage $V_1$ is a ramp waveform with its vertical portion synchronized with the zero crossings of the sinusoidal load voltage; $V_2$ is a dc error signal; and $V_3$ is a train of pulses that become wider as the error signal increases.

Figure 1. Power Saved is shown as averaged from tests made on a 1/3-hp split-phase motor and 1/4- and 3/4-hp capacitor-start motors. The top curve is the total power taken as a function of load with no control system. The bottom curve represents the total power with the voltage controlled by the circuit in Figure 2. Curves are plotted as percent of full power versus percent of full load. The circuit reduced the no-load power by a factor of 5 or 6 and increased the power factor from 0.2 to 0.8. In all three motors, the slowdown due to reducing the applied voltage was less than 2 percent.

When the pulse is positive, a voltage will be applied to the gate of the Triac.

The error signal is derived in the circuitry in the lower half of Figure 2.

(continued next page)
Figure 2. The Electronic Control Circuit consists of a typical phase-control circuit (top half) and a new circuit that senses the voltage/current phase lag in an ac inductor motor. This phase lag is used to produce an error signal (V2) for the phase-control circuit, where a control pulse is developed to switch a Triac that regulates the motor voltage in response to loads.

The phase lag between the voltage and current in the motor is sensed and is used to produce a dc voltage proportional to phase lag. This signal is fed back and summed with a power factor command signal. The difference between these two voltages is an error signal (V2) that drives amplifier A5 and controls the voltage to the motor.

This work was done by Frank J. Nola of Marshall Space Flight Center. For further information, Circle 3 on the TSP Request Card.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page A8]. Refer to MFS-23280.
1. **Title**

Power Factor Control System for Improved Efficiency in an AC Induction Motor

2. **Innovator(s)** (Name and Social Security No.)

Frank J. Nola

3. **Employer** (Organization and division)

NASA-MSFC
EC24

4. **Address** (Place of performance)

Marshall Space Flight Center, AL

5. **Documentation** (Full and complete disclosure must be enclosed, the contents of which are discussed in NASA 1700.3, Documentation Guidelines for New Technology Reporting. Place an "X" to the left of those items of documentation which are available but NOT enclosed with this transmission.)

<table>
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<th>Type</th>
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6. **Previous Publication or Public Disclosure**

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<th>Page</th>
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7. **State of Development**

- Concept Only
- Design
- Prototype
- Production Model
- Used in Current Work

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10. **Subcontract**

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<th>Subcontractor (CC 35-41)</th>
<th>Evaluation Organization (CC 52-56)</th>
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11. **Contractor/Grantee New Technology NOT Submitted Pursuant to NY/PRI Clause Provision (CC 36)**

12. **Prepared by**

<table>
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<tr>
<th>Name and Title</th>
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13. **Approved (Center TUV)**

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A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage to thereby provide less power to the motor, as it is less loaded.
### LICENSED MANUFACTURERS

For "Power Factor Control System for AC Induction Motors", U. S. Patent No. 4,052,648, NASA Case No. MFS-23280

<table>
<thead>
<tr>
<th>No.</th>
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<th>Phone Number</th>
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<tr>
<td>1.</td>
<td>Electronic Relays, Inc.</td>
<td>1438 Brook Drive, Downers Grove, IL 60515</td>
<td>Joseph Pacente</td>
<td>(312) 620-4646</td>
</tr>
<tr>
<td>2.</td>
<td>IVECO (Improvement Via Electronics Co.)</td>
<td>17402 Coronado LN, Huntington Beach, CA 92647</td>
<td>Edward Yrissari, Gen. Mgr.</td>
<td>(714) 842-2925</td>
</tr>
<tr>
<td>3.</td>
<td>W. J. Purcell Co.</td>
<td>4315 Myrtle Avenue, Cincinnati, OH 43236</td>
<td>Desmond J. Neville, Pres.</td>
<td>(513) 791-1131</td>
</tr>
<tr>
<td>4.</td>
<td>ADELET-PLM DIV.</td>
<td>423 Rita Street, Dayton, Ohio 45404</td>
<td>John Prikkel, P. E.</td>
<td>(513) 222-7749</td>
</tr>
<tr>
<td>5.</td>
<td>Electronic Assemblies Co.</td>
<td>1601 Hull Street, Richmond, VA 23224</td>
<td>Gerald F. Wilkinson</td>
<td>(804) 231-0132</td>
</tr>
<tr>
<td>7.</td>
<td>N.R.G. Products, Inc.</td>
<td>P. O. Box 512, Vineland, N. J. 08360</td>
<td>Fred L. Hurban</td>
<td>(609) 691-6699</td>
</tr>
<tr>
<td>8.</td>
<td>Clinton Industries, Inc.</td>
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<td>Angelo Pirrello</td>
<td>(201) 935-4242</td>
</tr>
<tr>
<td>10.</td>
<td>Controlled Power Corp.</td>
<td>2542 237th Street, Torrance, CA 90505</td>
<td>Fred A. Meyer, Jr.</td>
<td>(213) 539-5440</td>
</tr>
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</table>

Inquiries concerning licensing for commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center, Al 35812.
Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:
   - current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;
   - voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;
   - phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing an output which varies in accordance with the difference in phase between said current and said voltage;
   - control means adapted to be electrically connected in series with each said winding of said motor, and responsive to the output of said phase detection means for varying the duration of "on" time of each cycle of input power to said winding inversely proportional to the difference in phase between said current and said voltage;

whereby an increase in difference between the magnitude of said voltage and the magnitude of load applied to said motor is compensated for by a reduction in power to said motor, generally improving its efficiency.

2. A control system as set forth in claim 1 wherein said current sampling means includes a resistor adapter to be placed in series with a said winding and means for providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

4. A control system as set forth in claim 3 wherein said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

5. A control system as set forth in claim 4 wherein said control means includes:
   - means responsive to the voltage applied to said winding of said induction motor for providing a saw tooth wave at double the frequency of said voltage;
   - pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and
   - switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.
FIG. 2
FIG. 3

% OF FULL POWER (WATTS)

% OF FULL LOAD (TORQUE)

ORIGINAL PAGE IS OF POOR QUALITY.
POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art

The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Heretofore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal 115-volt service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention

It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will affect a reduction in power normally provided the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical schematic diagram of an embodiment of the invention. FIGS. 2a-2l are waveforms illustrating aspects of operation of the invention. FIG. 3 is a plot illustrating power drawn by a motor for different states of loading and with and without the control system of this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An AC induction motor 10 is powered by an alternating current voltage 12 (FIG. 2a) through switch 14 and connectible at terminals 16. The switched AC power is also applied to transformer 18 and circuit bias power supply 20. Triac 22 is connected in series with motor 10 and is triggered for controlled portions of each half cycle of input power. A small value resistor 24 of 0.010 to 0.020 ohms is connected in series with motor 10 and serves to develop a signal 26 (FIG. 2b) which is proportional to the current flow through the motor. FIG. 2b illustrates an instantaneous state of operation after initial start-up and with an initial optimum input voltage-load relationship, whereby triac 22 is fully on and where, thereafter, loading is substantially decreased. The initial current-voltage phase lag 28 for such optimum state of operation may vary from motor to motor and would be determined for each motor with which this invention is to be employed. In the present example, initially, optimum phase lag 28 is approximately 30°, and potentiometer 78 is adjusted to provide the zero error output signal for the control of the turn on time of triac 22 to maintain the phase angle of this or another selected value. The occurrence of increased current lag 28a at time T1 depicts a sudden decrease in loading of motor 10. The detection of this is used, as will be further explained, to reduce the average amplitude of input voltage and thereby to effect a commanded optimum phase lag.

To further examine the circuitry, transformer 18, having center tap secondary 32, provides oppositely phased inputs to square wave shapers 34 and 36, and the resulting oppositely phased outputs, square wave 38 (from shaper 36) shown in FIG. 2c and square wave 40 (from shaper 34) shown in FIG. 2d, which are fed to saw tooth or ramp wave shapers 42 and 44, respectively. The outputs of the wave shapers are combined to provide a ramp wave each half cycle of the alternating current input as shown in waveform 46 of FIG. 2k. Waveform 38 is also used as a reference signal for the phase of input voltage and is fed to one input of multiplier 48, functioning as a phase detector, to which is also fed a current reference signal 50 shown in FIG. 2g. The current reference signal is generated as follows. Current signal 36 (FIG. 2b) from resistor 24 is fed to isolation transformer 52 and from it to square wave pulse shaper 54, which provides square wave 56 (FIG. 2e). This square wave is differentiated in differentiator 58 to provide spike pulses 60 shown in FIG. 2f, and the negative pulses (derived from the trailing edge of square wave 56) are used to trigger one-shot 62, which provides as an output the square waveform 50 shown in FIG. 2g. This square waveform commences at a time corresponding to the trailing or zero crossing point of current signal 26 (FIG. 2b) and has a duration (determined by the time constant of one-shot 26) corresponding to the length of a half cycle of AC input to the motor. Thus, there is generated a square wave current signal which is of the
same duration as a half wave of voltage waveforms 12, 28, and 40, which is shifted in position proportional to the phase shift difference between current and voltage by virtue of the square wave current responsive signal being commenced at the precise end of (zero crossing) a half cycle of the current signal, which ending in time thus varies as a function of current lag.

Multiplier 48 multiplies voltage waveform 38 as shown in FIG. 2c with current waveform 50 shown in FIG. 2g to provide the product output waveform 64 shown in FIG. 2h. This output is integrated and reversed in sense in integrator 66. Except for this reversal, the output of integrator 66 would be maximum for conditions of no current lag and minimum for large current lags. To achieve the opposite sense, a reference voltage v3 was fed to one input of integrator 66 where it is negatively summed with the output of multiplier 48. As a result, the integrated output of integrator 66 is of a value 68, shown in FIGS. 2i and 2j, which varies in magnitude directly with phase angle. In other words, the greater the phase angle the greater the system error which is to be corrected. Output 68 (output 68a after time T3) of integrator 66, which is proportional to the phase angle, is fed to the negative input of operational amplifier 70.

To this same input is also applied an opposite polarity phase angle command voltage 69 (FIG. 2i), being applied through resistor 76 from potentiometer 78. Potentiometer 78 is calibrated to provide an output voltage representative of a desired phase angle to be commanded. Thus, when the system is operating with a commanded phase angle, the output of integrator 66 would be equal and opposite to the command signal from potentiometer 78, a condition shown by FIG. 2i as existing up to time T2. At this point, by virtue of increased output 64a from multiplier 48 because of increase phase shift 28, the output of integrator 66 increases negatively to a level 68a. Thus, there would initially be a net zero error voltage input 71 (FIG. 2j) to the negative input terminal of amplifier 70. Then, for the indicated phase lag in excess of the commanded phase lag, there would be a finite negative error signal 71a applied to this input, as shown. When this occurs, amplifier 70, which is a high gain amplifier, provides an amplified error signal 73a (FIG. 2k) to comparator 102 to effect such decrease in duty cycle of triac 22 necessary to retain the commanded, optimum, phase angle, in a manner to be described. As shown, this is effected during any interim between times T1 and T3.

In order to assure that when motor 10 is first turned on that it will develop maximum torque for a sufficient period to bring the motor up to speed, operation of the control system of this invention is initially delayed. This delay is achieved by delay circuit 80 consisting of capacitor 82 and resistor 84 connected in series between a bias output of power supply 20, which power supply is energized at the same time as motor 10, that is, by the closing of switch 14. Resistor 84 is connected between common ground and the positive input of operational amplifier 70. With a positive potential signal applied to capacitor 82, the initial charging current through resistor 84 is of a value sufficient (determined by the time constant of the combination of resistor 84 and capacitor 82) to override a maximum input applied to the negative terminal for a period of several seconds or longer, depending upon the application. A feedback circuit consisting of resistor 86 and capacitor 88, connected in parallel between the output of amplifier 70 and the negative input of the amplifier, provides the necessary gain and roll off frequency required for system stability.

Triac 22 is gated "on" by a gating signal coupled from the secondary of transformer 90 across an input of triac 22. This gating signal is a high frequency signal generated by oscillator 92 and applied to the primary of transformer 90 through gate or electronic switch 94. Resistor 96 and diode 98 are connected in series across the primary of transformer 90 in order to suppress inductive voltages to a safe level consistent with the semiconductors used. Gate 94 is triggered by pulses 100 (shown in FIG. 2l) and which illustrates "on" time of oscillator 92) from comparator 102 responsive to ramp waveform 46 (FIG. 2k) and control input signal 73 (FIG. 2k). Output pulses 100 from comparator 102 occur during the interval in which control signal 73 exceeds (is more positive than) ramp voltage 46. Thus, in the present example, the output of amplifier 70 initially provides a maximum (in a positive direction) output, and pulses 100 would have a 100 percent duty cycle extending over a full ramp period. This would gate "on" oscillator 92 and thereby triac 22 for the entire portion of input voltage cycle as initially shown for voltage waveform 30 in FIG. 2b. This, it will be assumed, continues for several seconds and until time T1, at which time the motor loading decreases to near zero. When this occurs, phase lag 28 would increase to some larger value of phase lag 28a, and this will increase, resulting in a shift to the right of current waveform 50 (FIG. 2g), which in turn will provide an increased width output pulse 64 from multiplier 48 (at time T2). In turn, this will provide an increase in the output of integrator 66 and input to amplifier 70, which will change from a zero level (level 71) to a discrete negative level (level 71a), as shown in FIG. 2j. As a result, amplifier 70 will provide an amplified, less positive, output error signal 73a commencing at time T2, as shown in FIG. 2k. When this occurs, comparator 102 provides a reduced width pulse 100a to gate 94, and it triggers "on" triac 22 for like decreased width periods to produce a change in input voltage, changing (at time T1) from that shown by waveform 30 to that shown by waveform 30a.

Thus, motor input voltage waveform 30 goes through a transition during the period of T1 to T3, having an initial phase lag 28 to an increased phase lag 28a and then back to the commanded phase lag 28, shifting from full width cycles 30 to extremely short width duration input cycles 30a. The shift in input voltage has been that necessary to re-establish the commanded currentvoltage phase lag, power factor, to thus maintain an optimum power input to motor 10. Had this not been done, the phase angle would have increased substantially, and thus the power factor would have decreased substantially, resulting in a significant waste of power.

FIG. 3 plots the percent of full power applied to motor 10 versus percent of full load, or torque, and line 112 illustrates a case where the control system of this invention is employed. Line 110 illustrates a case where it is not. The hatched difference between the lines is indicative of the power saved by employment of the invention.

While the invention illustrated herein is shown as being usable with a single phase device, it may be connected in circuit with each phase of a multi-stage induction motor. Thus, in the case of a Wye-connected three phase motor, three of the control systems illustrated in FIG. 1 will be employed, one being connected in each of the three phases with each referenced to ground (the
Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:
   current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;
   voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;
   phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing an output which varies in accordance with the difference in phase between said current and said voltage; and
   a control means adapted to be electrically connected in series with each said winding of said motor, and responsive to the output of said phase detection means for varying the duration of "on" time of each cycle of input power to said winding inversely proportional to the difference in phase between said current and said voltage;
   whereby an increase in difference between the magnitude of said voltage and the magnitude of load applied to said motor is compensated for by a reduction in power to said motor, generally improving its efficiency.

2. A control system as set forth in claim 1 wherein said current sampling means includes a resistor adapter to be placed in series with a said winding and means for providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein:
   said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding, and
   said current sampling means comprises means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

4. A control system as set forth in claim 3 wherein said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

5. A control system as set forth in claim 4 wherein said control means includes:
   means responsive to the voltage applied to said winding of said induction motor for providing a saw tooth wave at double the frequency of said voltage;
   pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and
   switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.
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<tr>
<td>ELECTRONICS AND CONTROL LABORATORY</td>
<td>POWER FACTOR CONTROLLER</td>
<td>FRANK NOLA</td>
<td>JUNE 1978</td>
</tr>
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</table>

**BACKGROUND**

0 ORGANIZATION

GUIDANCE, CONTROL AND INSTRUMENTATION DIVISION

ELECTRONICS AND SERVO ANALYSIS BRANCH

0 BECAME INVOLVED THROUGH MSFC'S SOLAR HEATING AND COOLING PROGRAM

0 INITIAL WORK DONE IN APRIL 1975

0 NOTIFIED IN MAY 1977 PATENT WOULD BE ISSUED

0 CONCEPT VERIFIED BY AUBURN UNIVERSITY

0 PATENT ISSUED OCTOBER 1977
ENERGY IN MOTORS

0 Study by A. D. Little Corp. indicates about two thirds of electrical energy generated is for motors.

0 This amounts to about 1100 billion kWh per year.

0 10 percent is in homes and 90 percent in industry.

0 Requires the equivalent of 6,000,000 barrels of oil per day.

0 Each percent energy to motors is reduced saves the equivalent of 60,000 barrels of oil per day.
INDUCTION MOTORS

0 DESIGNED FOR CONSTANT VOLTAGE AND CONSTANT FREQUENCY
0 RUN AT ESSENTIALLY CONSTANT SPEED REGARDLESS OF LOAD
0 CURRENT REMAINS HIGH AT NO LOAD CREATING LARGE INTERNAL LOSSES
0 NO LOAD CURRENT IN SINGLE PHASE MOTORS IS 70 TO 90% OF RATED LOAD CURRENT
0 NO LOAD CURRENT IN 3 PHASE MOTORS IS 50 TO 60% OF RATED LOAD CURRENT
0 PHASE ANGLE BETWEEN VOLTAGE AND CURRENT INCREASES WITH DECREASING LOAD
**CONCEPT**

- The device senses the line voltage and line current.
- Produces a voltage proportional (inversely) to phase angle between voltage and current.
- Compares this voltage with a commanded reference voltage indicative of a desired phase angle.
- Difference is an error voltage which biases a ramp that is in sync with the 60 Hz line voltage.
- Ramp and error are compared in a zero crossing detector (ZCD).
- The output of the ZCD forms the firing pulse for turning on a TRIAC in series with the motor.
- No modification required for single phase motors.
- Wye connected motors require connection to wye point.
Typical power savings for single phase motor
Bell & Gossett
1/2 HP 4 POLE

1/2 HP = 288 oz in
@ 1750 RPM

POWER (WATTS)

TORQUE (oz in)
1 HP, 220 V, 1 HP
175 RPM, 3.4 Amps
GE
Torque F. = 55 in. lb
Power in G F. = 740 W

Input

5. Input vs. Output (G F.)

Original page is of poor quality.

Percent Full Load Torque
Percent Savings at Various Loads

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<th>FULL LOAD</th>
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<td>5 HP Pacer</td>
<td>0%</td>
<td>4%</td>
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Tabulated from Auburn Data

All 3 HP Motors

Manual Phase Control
TEXTILE MILL APPLICATION

BREADBOARD CONTROLLER WHICH WAS GOVERNMENT FURNISHED TO AUBURN WAS TESTED IN A TEXTILE MILL.

MILL HAS 3700 SEWING MACHINES.

EACH MACHINE HAS A 1/2 HP AMCO 3-PHASE MOTOR WITH WYE CONNECTION EXTERNAL TO MOTOR FOR CONNECTING TO LIGHT.

PLANT RESEARCH ENGINEER INDICATED THIS IS AN INDUSTRY STANDARD MOTOR SELECTED FOR HIGH PERFORMANCE AND RELIABILITY AND ESTIMATES 90% USAGE IN TEXTILE INDUSTRY.

COST $80 WITH CLUTCH.

CONTROLLER WAS CONNECTED TO ONE MACHINE. THIS MACHINE AND A SECOND MACHINE WERE INSTRUMENTED FOR MEASURING POWER CONSUMPTION.

A TYPICAL 20 DUTY CYCLE WAS SIMULATED FOR BOTH MACHINES.

BOTH MACHINES RUN 24 HRS A DAY FOR 21 DAYS

MACHINE EQUIPPED WITH CONTROLLER INDICATED ABOUT 33% LESS POWER CONSUMPTION.
TO BE DETERMINED

0 Potential this circuit has for saving energy
0 Cost to produce the device - both single and 3 phase
0 Cost effectiveness of applying the device
0 Can the device aid in cutting costs charged for a poor power factor? Can it replace capacitors and synchronous motors used for correction.
0 In certain applications can the device double as the power controller for the motor?
0 Can the device serve as a means of limiting starting inrush current in large motors?
0 Potential for reducing air conditioning costs?
0 How serious is the problem of connecting to the wye point of 3 phase wye motor?
0 Is the wye point available in larger motors?
0 Effect on utilities distribution system
0 Is the savings to the utility company significant?
0 Stability needs to be analyzed
0 Ability to respond to step type loading needs to be studied and improved
0 In some cases the capacitor required for stability needs to be larger than that required for filtering. This slows the response.
TO BE DETERMINED (CONT'D)

0 In some cases there has been a misfiring of the triac

0 Balancing of the 3 error signals in 3 phase motors may be a problem

0 Possibility of eliminating the need for connecting to the wye point needs investigating
The patent is somewhat difficult to read and the circuitry it describes, we have since learned, is more complex than required.

is unloaded or partially loaded. Six single phase motors we tested showed unloaded current to be about 90% of the rated load current. Four three-phase motors (5 Hp down) showed the no load current to be about 50 to 60% of rated load current. These currents cause heat losses in the motor and in the utilities distribution system. Large users of motors with cyclic loads are often charged for a poor power factor.

Since the current remains high in an unloaded motor, the phase angle between voltage and current shifts with load. Typically the current may lag the voltage 80° in an unloaded motor and 30° when loaded. The power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference of the two produces an error signal which biases a ramp voltage that is in sync with the 60 Hz line voltage. The intersection of the ramp and the error voltages are detected by a squaring amplifier whose output provides the timing for turning on a triac (or SCR's) in the motor line.

Thus the "on" time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the attached timing diagram.

The phase angle shown as $\theta$ in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

In the circuit, amplifiers A1 and A2 produce a square wave and its inverse which are in sync with the zero crossings of the voltage. These are $E$ and $\bar{E}$ in the timing diagram.

The current waveform which is sensed by the resistor (R20) transformer (T3) combination or by a current transformer is squared by amplifiers A5 and A6 to produce $I$ and $I'$. $\bar{E}$ is AND'ed with $I$ and $E$ is AND'ed with $I'$. These two outputs are OR'ed to produce the voltage which is representative of the phase angle between voltage and current.

This voltage is filtered and summed with the command voltage in amplifier A7. The output is the system error signal and is compared with the ramp voltage in Amplifier A3. The error is shown superimposed on the
The patent is somewhat difficult to read and the circuitry it describes, we have since learned, is more complex than required.

is unloaded or partially loaded. Six single phase motors we tested showed unloaded current to be about 90% of the rated load current. Four three-phase motors (5 Hp down) showed the no load current to be about 50 to 60% of rated load current. These currents cause heat losses in the motor and in the utilities distribution system. Large users of motors with cyclic loads are often charged for a poor power factor.

Since the current remains high in an unloaded motor, the phase angle between voltage and current shifts with load. Typically the current may lag the voltage 80° in an unloaded motor and 30° when loaded. The power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference of the two produces an error signal which biases a ramp voltage that is in sync with the 60 Hz line voltage. The intersection of the ramp and the error voltages are detected by a squaring amplifier whose output provides the timing for turning on a triac (or SCR's) in the motor line.

Thus the "on" time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the attached timing diagram.

The phase angle shown as θ in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

In the circuit, amplifiers A1 and A2 produce a square wave and its inverse which are in sync with the zero crossings of the voltage. These are E and E in the timing diagram.

The current waveform which is sensed by the resistor (R20) transformer (T3) combination or by a current transformer is squared by amplifiers A5 and A6 to produce I and I'. E is AND'ed with I and E is AND'ed with I'. These two outputs are OR'ed to produce the voltage which is representative of the phase angle between voltage and current.

This voltage is filtered and summed with the command voltage in amplifier A7. The output is the system error signal and is compared with the ramp voltage in Amplifier A3. The error is shown superimposed on the
ramp in the timing diagram. The intersection of the error voltage and the sloped portion of the ramp form the turn on time for the triac. The triac remains on until the current passes through zero for each half cycle. C7 and R27 are a starting override that commands full voltage for starting the motor.

The circuit described by the patent and shown in the tech brief functions in a similar manner. The current waveform is squared only once as shown by I in the timing diagram. The falling edge of the squared pulse contains the phase angle information. This waveform is differentiated to form trigger pulses which are fed to a one shot. The one shot is sensitive only to the negative trigger (falling edge) and the transition time is set to be equal to a half cycle of 60 Hz. Thus a symmetrical square wave is produced which contains the phase shift information. This square wave is fed to one input of a multiplier. The line voltage is squared and fed to the second input. The output of the multiplier is similar to the ORed voltage shown in the timing diagram. The remainder of the circuit functions identical to that previously described. Amplifier A8 shown in the tech brief and called integrator (66) in the patent is not required and has been eliminated.

Most of the testing of the power factor control circuit has been done with motors loaded by a dynamometer. The response time of the dynamometer is a few tenths of a second. The stability of the system for step type loading needs investigating. The response time of this circuit is limited by the filter time constant required to smooth the phase angle voltage (output of U4C).

Our test has shown that the slow down of a fully loaded motor with this circuit in control is less than 2%.

Single phase motors require no modifications to apply this controller. With wye connected 3-phase motors, we have found it necessary to connect to the wye internal to the motor. A triac with its firing circuitry is placed in series with each phase of the motor. The phase angle is sensed in only one phase and the error signal controls the 3 phases. To our knowledge the circuit has not been tried with a delta connected motor. We believe it will be necessary to place the triac in series with each winding inside the delta. Two voltage delta motors have all the necessary leads external to the motor so that no internal modification would be required.

We believe that in certain applications, the cost effectiveness of applying this controller could be enhanced by having the circuit (with slight modifications) serve also as the on-off contactor for a motor or as a means of limiting starting inrush current in larger motors.
Line Voltage

Motor Voltage

Motor Current

E

V₄

V₅

V₆

E \times V₆
### DESCRIPTIONS OF END-USER CATEGORIES

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<th>SIC</th>
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<td>Crops, Livestock, Agric. Services, Forestry and Fishing</td>
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<td>Mining</td>
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**APPENDIX F**

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**IVECO**

IMPROVEMENT VIA ELECTRONICS

17402 Coronado Lane
Huntington Beach, CA 92647

**TRIAC SELECTION**

SINGLE PHASE MPC

MODEL BY 10Z1

DD - 0012

Page 1 of 3
### TRIAC SELECTION - 1Φ MPC

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### NOTES:

1. Refer to IVECO DD-0013 for Heat Sink A
   Refer to IVECO DD-0013 for Heat Sink B
   Refer to IVECO DD-0013 for Heat Sink C
2. Calculations based on:
   \[ I_{FLA} = \frac{V(MOT)(\text{off} \cdot \text{pf})}{(746)HP} \]
   where: \((\text{off} \cdot \text{pf}) = 0.75\)
3. All triacs are isolated types.

---

**SINGLE PHASE MPC TRIAC SELECTION**

P2053  DD - 0012

---

Edward H. John

CEO
# Definitions

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<th>Description</th>
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<tr>
<td>HP</td>
<td>Horsepower</td>
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<tr>
<td>FLA</td>
<td>Full Load Amps (associated with motors)</td>
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<tr>
<td>V(mot)</td>
<td>Motor Voltage (line)</td>
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<tr>
<td>PD</td>
<td>Power Dissipation in triac element (or SCR) inlet</td>
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<td>IT</td>
<td>Triac steady-state current maximum</td>
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<tr>
<td>V( DEM)</td>
<td>Triac OFF-state maximum voltage</td>
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<td>HS</td>
<td>Heat Sink</td>
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APPENDIX G

NASA PATENT 4,052,648
A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage to thereby provide less power to the motor, as it is less loaded.

5 Claims, 3 Drawing Figures
FIG. 2
FIG. 3

ORIGINAL PAGE IS OF POOR QUALITY.
POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

1. Field of the Invention

This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art

The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Herefore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal 115-volt service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention

It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will effect a reduction in power normally provided the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phrase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.
same duration as a half wave of voltage waveforms 12, 38, and 40, which is shifted in position proportional to the phase shift difference between current and voltage by virtue of the square wave current responsive signal being commenced at the precise end of (zero crossing) a half cycle of the current signal, which ending in time thus varies as a function of current lag.

Multiplier 48 multiplies voltage waveform 38 as shown in FIG. 2c with current waveform 50 shown in FIG. 2g to provide the product output waveform 64 shown in FIG. 2a. This output is integrated and reversed in sense in integrator 66. Except for this reversal, the output of integrator 66 would be maximum for conditions of no current lag and minimum for large current lags. To achieve the opposite sense, a reference voltage \( V_0 \) is fed to one input of integrator 66 where it is negatively summed with the output of multiplier 48. As a result, the integrated output of integrator 66 is of a value \( V_0 \), shown in FIGS. 2i and 2j, which varies in magnitude directly with phase angle. In other words, the greater the phase angle the greater the system error which is to be corrected. Output \( V_0 \) (output \( V_0 \) after time \( T_2 \)) of integrator 66, which is proportional to the phase angle, is fed to the negative input of operational amplifier 70.

To this same input is also applied an opposite polarity phase angle command voltage \( V_{\text{cmd}} \) (FIG. 2), being applied through resistor 76 from potentiometer 78. Potentiometer 78 is calibrated to provide an output voltage representative of a desired phase angle to be commanded. Thus, when the system is operating with a commanded phase angle, the output of integrator 66 would be equal and opposite to the command signal from potentiometer 78, a condition shown by FIG. 2j as existing up to time \( T_2 \). At this point, by virtue of increased output \( 64a \) from multiplier 48 because of increase phase shift 28, the output of integrator 66 increases negatively to a level \( 68a \). Thus, there would initially be a net zero error voltage input to integrator 66. Then, for the indicated phase lag in excess of the commanded phase lag, there would be a finite negative error signal \( 71a \) applied to this input, as shown. When this occurs, amplifier 70, which is a high gain amplifier, provides an amplified error signal \( 71a \) (FIG. 2k) to comparator 102 to trigger gate 94, and it triggers “on” triac 22 for like decreased width pulses \( 45 \) and \( 100 \), which would provide an increased width output pulse \( 64 \) from multiplier 48 (at time \( T_2 \)). In turn, this will provide an increase in the output of integrator 66 and input to amplifier 70, which will change from a zero level (level \( 71a \)) to a discrete negative level (level \( 71a^2 \)) as shown in FIG. 2j. As a result, amplifier 70 will provide an amplified, less positive, output error signal \( 73a \) commencing at time \( T_2 \), as shown in FIG. 2c. When this occurs, comparator 102 provides a reduced width pulse \( 100 \) to gate 94, and it triggers “on” triac 22 for like decreased width periods to produce a change in input voltage, changing (at time \( T_3 \)) from that shown by waveform 30 to that shown by waveform 30a.

Thus, motor input voltage waveform 30 goes through a transition during the period of \( T_1 \) to \( T_3 \), having an initial phase lag 28 to an increased phase lag 28a and then back to the commanded phase lag 28, shifting from full width cycles 30 to extremely short width duration input cycles 30a. The shift in input voltage has been that necessary to re-establish the commanded current-voltage phase lag, power factor, to thus maintain an optimum power input to motor 10. Had this not been done, the phase angle would have increased substantially, and thus the power factor would have decreased substantially, resulting in a significant waste of power.

FIG. 3 plots the percent of full power applied to motor 10 versus percent of full load, or torque, and line 112 illustrates a case where the control system of this invention is employed. Line 110 illustrates a case where it is not. The hatched difference between the lines is indicative of the power saved by employment of the invention.

While the invention illustrated herein is as being usable with a single phase device, it may be connected in circuit with each phase of a multi-stage induction motor. Thus, in the case of a three phase motor, three of the control systems illustrated in FIG. 1 will be employed, one being connected in each of the three phases with each referenced to ground (the
APPENDIX F

ENCLOSURE CONFIGURATIONS

NEMA 1
NEMA 3R

Also added to Table of Contents
Notes:
1. Enclosure is Wiegman PN SC463 NK
   Cover (outside heatsink) PN SCF46 "cover A"
   Cover (inside heatsink) PN SCF46 "cover B"
2. Pgs 1 thru 9 identified as SK 081480-1 thru SK 081480-B
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<td>SK081480-8</td>
<td>LEFT/RIGHT VIEW</td>
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IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

DR: Effimann
8/14/80
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Notes:

- TOP also referred to as COVER (FLASH)
- Special Wiemmann Pull Box 6"x4"x3" DRILLED
- See SK081480-8 "BRACKET"
- TUB same for Enclosure A" or B"
ITEM | P/N
---|---
1 | SC463NK
2 | SCF4L
3 | BXT 1

NOTES:

⚠️ TOP also referred to as COVER (FLUSH)
⚠️ NOT TO SCALE
⚠️ Special IVECO/Wiegmann Pull Box 6" x 4" x 3" Drilled,
⚠️ See SK081480-B "BRACKET"
⚠️ TUB same for Enclosure A or B

ENCLOSURE "B"

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647
SK081480-2
ENVELOPE FRONT VIEW

IVECO
IMPROVEMENT VIA ELECTRONICS
27402 Coronado Lane
Huntington Beach, CA 92647

SK081480-3
**NOTES**

1. Datum is lower left corner.
2. The 1 3/16" dim must be held with respect to hole in bottom (3/8" Ref) to 0.010".
3. Special IVECO Wiegmann Pull Box 6"x4"x3" DRILLED.
4. Tub used on either enclosure "A" or "B".

**ITEM | P/N**

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**ENCLOSURE**

**BACK VIEW**

**EY1021**

IVECO

IMPROVING IT VIA ELECTRONICS

17402 Coronado Lane

Huntington Beach, CA 92647

SK 0814BO-4
### Section "A"

**Top View**

- **NOTES:**
  - Not To Scale
  - 0.164" Dia
  - TYP 2 PL
  - used on Enclosure "A" config only.

**Item** | **P/N**
---|---
2 | SCF 46

**COVER "A"**

**FLUSH COVER EY1021**

*IVECO*

**IMPROVEMENT VIA ELECTRONICS**

17402 Coronado Lane
Huntington Beach, CA 92647

*SK 081480-5*
NOTES B

⚠ Lower left corner is datum.
⚠ Ref for all dims are outside edges.
⚠ Hold relationship of these holes ± 0.010 "
⚠ Special IVECO/Wiegmann Pull Box 6" x 4" x 3" drilled.
Notes 8

△ NOT TO SCALE
△ Special IVECO/Wiegmann Pull Box, 6" x 4" x 3" Drilled.
△ 12 or 14 gauge steel, std. grey paint.
STUD/TO-3 FLANGE PRESS-FIT
SC240, 45, 50, 60, 65 SC241, 46, 51, 61, 66

NOTES:
1. GATE CONTROL MAY BE LOST DURING AND IMMEDIATELY FOLLOWING THE SURGE CURRENT INTERVAL.
2. CURRENT OVERLOAD MAY NOT BE REPEATED UNTIL JUNCTION TEMPERATURE HAS RETURNED TO WITHIN STEADY-STATE RATED VALUE.


NOTES:
1. GATE CONTROL MAY BE LOST DURING AND IMMEDIATELY FOLLOWING THE SURGE CURRENT INTERVAL.
2. CURRENT OVERLOAD MAY NOT BE REPEATED UNTIL JUNCTION TEMPERATURE HAS RETURNED TO WITHIN STEADY-STATE RATED VALUE.
T6400, T6410, T6420 Series

**LOAD: RESISTIVE**

RMS ON-STATE CURRENT \( I_{(RMS)} \) 40 A AT SPECIFIED CASE TEMP.

GATE CONTROL MAY BE LOST DURING AND IMMEDIATELY FOLLOWING SURGE CURRENT INTERVAL. OVERLOAD MAY NOT BE REPEATED UNTIL JUNCTION TEMPERATURE HAS RETURNED TO STEADY-STATE RATED VALUE.

Fig. 4 — Peak surge on-state current vs. surge current duration.

---

T6401, T6411, T6421 Series

**LOAD: RESISTIVE**

RMS ON-STATE CURRENT \( I_{(RMS)} \) 30 A AT SPECIFIED CASE TEMP.

GATE CONTROL MAY BE LOST DURING AND IMMEDIATELY FOLLOWING SURGE CURRENT INTERVAL. OVERLOAD MAY NOT BE REPEATED UNTIL JUNCTION TEMPERATURE HAS RETURNED TO STEADY-STATE RATED VALUE.

Fig. 4 — Peak surge on-state current vs. surge current duration.
APPENDIX J

THERMAL ANALYSIS, 3Ø CONTROLLERS, 100°F/80°F
Revised Calculation

Assuming 100°F ambient and 10°F margin on the heat sink.

Case To Heat Sink Thermal Resistance:

a) \( \frac{1}{4} \)" Stud - 1/16 HEX (80109)
   - 05 - .29
   - 17 - .56
   - AHAM
   - HAC - 1200 OH

\( \frac{1}{4} \)" Stud - 1/16 HEX (C11212)
   - 07 - .48
   - 28 - .55
   - 16 - .15
   - 6
   - 4
   - AHAM (Eq 12)
   - HAC & 1200 GR.
   - RCA (New Data)
   - RCA (Old Data)
   - 6°F (Ref Telecom)

- Assume \( 15 \text{°C/Watt} \) for all
- \( \frac{1}{4} \) 9/16 HEX Devices (RC-HR, 5°F)

b) \( \frac{1}{2} \) 20° Stud \& 1/16 HEX
   - 05 - .15
   - 07 - .22
   - OP - .26
   - RCA
   - AHAM
   - HAC - 1200 OH

- Assume .2°C/W
I

1 HP, 240 Volts

Using an SCR40 (T2 max = 100°C),
Tj = 89°C from a prior calculation
- no heat sink required

II

5 HP - 480 Volts

T rms/ leg = 7.4 amperes
Using TRON - one diode per leg
Pd = 5 watts
Tmax = 110°C

Tj max = Tj - ER
       = 100°C - 5(ER)

Rg - c = 1.0 °C/μA
Rc - hr = 5 °C/μA

Tj max = 100°C - 5(1.0 + 5) = 92.5°C
Assuming on E105 heat sink

6" Long = 3 holes per heat sink

\[ P_d = 3(i) = 11.715 \]

\[ P_d = 51.15 \]

\[ \theta_0 = 73.44 \]

Looking at the form factor of the E105 Heat Sink

\[ R_1 = 1.640 (2) + 3.937 = 2.713 \]

\[ \frac{A5}{12} = 21.063 \]

\[ R_2 = 21.063 - 2.713 = 13.75 \]

\[ \frac{13}{16} \]

\[ \frac{13}{16} \]

\[ L = 6.0, \theta = .4, 45.45, 105 \]

\[ \theta = .4 \]

\[ R_1 = \frac{L}{D} = \frac{6}{.4} = 15 \]

\[ R_2 = \frac{10}{12} = 1.814 = 3.25 \]

\[ F_n = 1.21 = .28 \]

\[ \theta = .45 \]

\[ R_1 = \frac{L}{D} = \frac{6}{.45} = 13.33 \]

\[ R_2 = 1.33 = 2.17 \]

\[ F_n = 1 - 1.68 = .38 \]
c) \( d = 1.05 \)

\[ R_1 = \frac{d}{b} = \frac{6}{1.35} = 4.44 \]

\[ R_2 = \frac{v}{1.3} = \frac{6}{1.35} = 4.6 \]

\[ F_n = 1 - 0.34 = 0.66 \]

\[ 0.66 \left( \frac{-26}{} + 2(35) + 66 \right) = 0.396 \text{ in.} \]

\[ F_n = 0.40 \]

\[ T_h = 107.2^\circ F \]

\[ \delta_t = 51.1^\circ F \]

\[ \begin{array}{c|c}
150 & 73.1 \\
140 & 56.1 \\
130 & 52.2 \\
130 & 51.1^\circ F \\
\end{array} \]

\[ s = T_h + \delta_t = 107.2 + 51.1 = 158.3^\circ F (65^\circ C) \]

III 5 HP 240 volts

\[ I_{rms/leg} = 14.8 \text{ amps} \]

Using one SC260 diode per leg

\[ P_{diode} = 14 \text{ watts} \]

\[ P_d = 1.55 \text{ watts/amp} \]

\[ I_{max} = 110^\circ F \]

\[ T_{h, max} = T_j - Q \delta R = 105 - 14(35^\circ F) = 77.7^\circ F \]
Assuming 2100 hrs - 6” Long

\[ \Sigma P_d = 14 \times (0.41)(2100) = 140.22 \]

\[ \Sigma P_d = 143.22 \]

<table>
<thead>
<tr>
<th>THS</th>
<th>EPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>91.09</td>
</tr>
<tr>
<td>170</td>
<td>109</td>
</tr>
<tr>
<td>190</td>
<td>149</td>
</tr>
<tr>
<td>175</td>
<td>109.9</td>
</tr>
<tr>
<td>187</td>
<td>143</td>
</tr>
</tbody>
</table>

\[ T_2 = THS + \Sigma EP_d = 187 + 14(0.94)(0.8) = 225.59°C \]

If \( L = 6.25" \)

\[ \Sigma P_d = 140 \]

\[ THS = 185°F \]

If \( L = 7.2" \)

\[ \Sigma P_d = 136 \]

\[ THS = 160°F \quad \text{STILL EXCESSIVE} \]

If \( L = 8" \)

\[ \Sigma P_d = 140 \]

\[ THS = 151°F \]

and is acceptable

\[ T_2 = 171 + 14(0.95)(0.8) = 230.17°F \]

Rev. 1/15 - 6" x 2" x 4"
Consider an E860 HS -

\[ P_1 = 6.500 + 16(2) = 97 \text{ in}^3/\text{in} \]

\[ A_{1/4} = 43.8 - 6.5 = 36.7 \text{ in}^2/\text{in} \]

\[ P_2 = 36.7 - 97 = 27 \]

\[ L = 6'' \]

Checking \( A_{1/4} = \)

\[ 6.500 + (1.6 - 2)(1.1)(2) = 32.3 \text{ in}^2 \]

Then \( P_2 = 32.3 - 97 = 22.3 \]

\[ L = 6.0'' \]

\[ 160 \quad 144.86 \]

\[ 159 \quad 141.93 \]

\[ = TH = 150 \text{ °F} \]

\[ T_2 = TH + 39.6 = 160 + 14(19.8)\text{ °F} \]

\[ = 309.14 \text{ °F (94.4 °C)} \]

\[ E \text{ 860 cost} = 6.50 / \text{foot} \]

\[ E \text{ 103 cost} = 3.65 / \text{foot} \]

\[ L = 5.12'' \]

\[ 165 \text{ °F} \]

\[ 170 \quad 149 \]

\[ 167 \quad 142 \]

\[ 164 \quad 144.6 \]

\[ T_2 = 164 + 14(1.95)\text{ °F} = 212.17 \text{ °F (100.5 °C)} \]
If an SC261 is considered:

\[ \text{Trms/leg} = 14.8 \text{ cm/hr} \]
\[ Pd/choke = \text{Cone choke per leg} = 12 \text{W} \]
\[ P_2 - C = 1.10 \text{ °C/hr} \quad R_{ch} = 4.5 \text{ °C/hr} \]

\[ T_{th} = T_j - 0.25^\circ = 105^\circ - 12(110 + 4) \]
\[ T_{th} \text{ max} = 97^\circ \text{C (182°F)} \]

Assuming an E360 section (\( L = 4'' \))

\[ \text{SPD} = 12 (2)(0.45) = 12.276 \text{ °C/hr} \]

\[ \begin{array}{c|c}
L = 4'' & \text{SPD} = 12.276 \\
180 & 146.4 \\
175 & 135.25 \\
170 & 124.26 \\
169 & 122.09 \\
\end{array} \]

\[ T_j = 169 + 12(0.5)(0.45) = 201.4^\circ F \text{ (94°C)} \]

\[ T_{th} = 169^\circ F \]

\[ \begin{array}{c|c|c}
L = 35 & T_{th} & \text{SPD} = 122.76 \\
180 & 130 \\
175 & 120 \\
177 & 124.92 \\
176 & 122.9 \\
\end{array} \]

\[ T_j = 176 + 12(0.5)(0.8) = 208^\circ F \text{ (98°C)} \]
Could use three SC265's and one E103 section 3.5" long

Assuming E103 section L=6"

THS EPd = 12276

| L=6" | 170 | 109.8 |
|      | 140 | 129.37 |
|      | 175 | 119.51 |
|      | 177 | 123   |
|      | 176.5 | 122.4 |

\[ T = 50^\circ C \]

Cut Summary -

<table>
<thead>
<tr>
<th>Diode</th>
<th>Cut x 3</th>
<th>HS</th>
<th>Cut HS</th>
<th>THS</th>
<th>EPd</th>
<th>ECUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC260</td>
<td>11.01</td>
<td>E103-8</td>
<td>2.43</td>
<td>105°C</td>
<td>12376</td>
<td>13.44</td>
</tr>
<tr>
<td>SC260</td>
<td>11.01</td>
<td>E103-5</td>
<td>2.63</td>
<td>103°C</td>
<td>12376</td>
<td>13.67</td>
</tr>
<tr>
<td>SC265-</td>
<td>10.72</td>
<td>E103-6</td>
<td>1.83</td>
<td>94°C</td>
<td>12376</td>
<td>14.55</td>
</tr>
<tr>
<td>SC265-</td>
<td>12.72</td>
<td>E103-3</td>
<td>1.03</td>
<td>98°C</td>
<td>12376</td>
<td>14.55</td>
</tr>
</tbody>
</table>

(1) E103 Section - 5" Long - SC265 (High)

THS EPd = 12276

| 180 | 110.6 |
| 140.5 | 125 |

- Use the 6" long version

1C SC265 Triacs, E103-6 HS.
Three Triacs per heatsink.
II(b) Considering the 5HP-410 VST condition again -

\[ P_d = 51.5 \]

<table>
<thead>
<tr>
<th></th>
<th>T45</th>
<th>EPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>46.05</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>51.64</td>
<td></td>
</tr>
</tbody>
</table>

\[ T_{HS} = 155^\circ F \]

\[ T_2 = 155 + 5 \times (1.5) \times (46.05) = 162.5^\circ F (72.5^\circ C) \]

- Could use T64200 Cone (1.24 x 0.4) & E103 HS 3.5" long, 3 Transient per hrs.

If consider no heat sink -

\[ P_d / L_5 = \sqrt{\text{Watt}} \]

\[ T_{HS} = (19125^\circ F \text{ max}) \]

\[ EPd = 5 \times (3) \times (3.4) = 51.15 \text{ BTU/hr} \]

\[ P_1 = 6.0, P_2 = 6.0, F_n = 1.0 \]

\[ T_4F = 100, L = 8" \]

\[ A = 6 \times 8 = \frac{48}{8} = 6 \]

<table>
<thead>
<tr>
<th></th>
<th>T45</th>
<th>EPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>64.68</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>51.4</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>49.1</td>
<td></td>
</tr>
<tr>
<td>146</td>
<td>50.3</td>
<td></td>
</tr>
<tr>
<td>147</td>
<td>51.6</td>
<td></td>
</tr>
</tbody>
</table>

\[ \therefore T_{HS} = 147^\circ F \]
\[ h_c = 0.84 \text{ (Ref 12)} \quad h_r = 1.23 \]

\[ Q = 5 \cdot m \cdot A_c \cdot \theta_0 \cdot \tanh(mL) \]

\[ h = 0.84 + 1.23 = 2.07 \]

\[ m = \sqrt{\frac{h \cdot c}{k \cdot A_c}} = \sqrt{\frac{(2.07)(6)(144)}{12(2.07)(0.06)(6)}} = 3.916 \]

\[ \frac{5(3.916)(2)}{2} = \frac{(27)(3.916)(6)(0.06)}{144} \cdot \tanh\left(\frac{3.916 \times 4}{12}\right) \]

\[ \theta_0 = 112^\circ F \]

\[ T_h = 100 + 112^\circ F = 210^\circ F \text{ (exclusive)} \]

- a heat sink is required

Assume an E109 heat sink

\[ L = 4'' \text{ long} - \quad \text{EPD} = 51.15 \]

\[ \sqrt{T_{hs}} \quad \text{EPD} = 51.15 \]

\[ 16^\circ \quad 64.3 \]

\[ 150 \quad 51.62 \quad : \quad T_{hs} = 150^\circ F \]

\[ T_2 = T_{hs} + \xi QR = 150 + 5(1.0 + 5)(1.1) \]

\[ = 163.5^\circ F \text{ (23\%)} \]
IV

10 HP 410 Volts

Inmr./leg = 13.0 amperes
Using one T6420 on Trial per leg
Pd = 9.5 watts
Ps-c = 60 °C/m Ps-hw = 55 °C/m

T/hr max = T_j = QER = 100 - 9.5 (10 + 5)
= 85.75 °C (186.35 °F)

Assuming an E123 section - 6" long
Three diodes per H.S.

ΣPd = 9.5 (3.41) (3) = 97.145

\[ \frac{T_{HR}}{3Pd} = 97.145 \]

L = 6"

170°F 109.34
165°F 100.36
164°F 98.49
163°F 96.63
162.5°F 95.56

\[ T_j = T_{HR} + QER = 163.5 + 9.5 (10 + 5) \times 0.2 \]

= 189.15°F (87.80 °C)
If L = 4.0 x 10^3 \text{ cm}, Pd = 97.145

<table>
<thead>
<tr>
<th>T/hr</th>
<th>5Pd = 97.145</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>77.57</td>
</tr>
<tr>
<td>180</td>
<td>91.38</td>
</tr>
<tr>
<td>182</td>
<td>93.21</td>
</tr>
<tr>
<td>183</td>
<td>95.68</td>
</tr>
<tr>
<td>184</td>
<td>97.01</td>
</tr>
</tbody>
</table>

\[ T = 184 + 9.5C \times 15 \times 10 = 209.7^\circ C \] (98%)

Use the 6" length for the sake of uniformity and added reliability.

\[ 10 \text{ HP - 240 Volt} \]

\[ \text{Inrush/leg} = 25.9 \text{ amperes} \]

Assuming 2 diodes per line - Type 5C265

\[ \text{Inrush/diode} = 13.0 \text{ amperes} \]

\[ \text{Pd/diode} = 10 \text{ watts} \]

\[ P_2 = 1.10 \text{ wt/m Watt} \]

\[ RC-\text{hr} = -1.4^\circ C/\text{hr} \]

\[ THR = T - QER = 105 - 10(1.10 + .0) \]

\[ = 90^\circ C (194^\circ F) \text{ max.} \]

Assuming again on E360 HS - 6" long

6 diodes per HS - Pd/HR = 60 watts.
\[ \text{EPd} = 60 \times (3.41) = 204.6 \]

<table>
<thead>
<tr>
<th>THS (°F)</th>
<th>EPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>144.86</td>
</tr>
<tr>
<td>170</td>
<td>174.12</td>
</tr>
<tr>
<td>180</td>
<td>206.00</td>
</tr>
<tr>
<td>179</td>
<td>202.53</td>
</tr>
</tbody>
</table>

\[ \text{THS} = 179°F \]
\[ T_2 = 175°F + 10(110 + 4)(10) = 206°F \]

IV

20 HP - 440 Volts

\[ \text{Input/leg} = 25.9 \text{ amps} \]

If one 6400 N Triac is used per leg
\[ P_d = 24 \text{ watts per phase} \]
\[ T_{2max} = 110°F \]
\[ P_2-c = 1.0 \text{ °C/W} \]
\[ R_c-hts = 0.5 \text{ °C/W} \]
\[ \text{THS}_{max} = T_2 - Q_{ER} = 100°F - 24(1.5) = 64°F (142°F) \]

Assume 2.360 Hrs - 6" Long
\[ \text{EPd} = 24(3)(3.41) = 245.52 \]

<table>
<thead>
<tr>
<th>THS</th>
<th>EPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.0</td>
<td>63.2</td>
</tr>
<tr>
<td>150</td>
<td>116</td>
</tr>
</tbody>
</table>

\[ \text{L = 6"} \]
\[ \text{6" is not long enough} \]
### E860-8

<table>
<thead>
<tr>
<th>THS</th>
<th>EPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>18.6</td>
</tr>
<tr>
<td>160</td>
<td>18.4</td>
</tr>
</tbody>
</table>

\[ THS > 142.3°F \]

### E860-10

<table>
<thead>
<tr>
<th>THS</th>
<th>EPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>13.7</td>
</tr>
<tr>
<td>150</td>
<td>17.9</td>
</tr>
<tr>
<td>160</td>
<td>22.3</td>
</tr>
<tr>
<td>165</td>
<td>24.6</td>
</tr>
</tbody>
</table>

\[ THS = 165°F (Too hi) \]

### E860-12

<table>
<thead>
<tr>
<th>THS</th>
<th>EPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>7.1</td>
</tr>
<tr>
<td>140</td>
<td>16.0</td>
</tr>
<tr>
<td>150</td>
<td>20.9</td>
</tr>
<tr>
<td>160</td>
<td>26.1</td>
</tr>
<tr>
<td>155</td>
<td>23.5</td>
</tr>
<tr>
<td>157</td>
<td>24.5</td>
</tr>
</tbody>
</table>

\[ THS = 157°F \]

\[ & \text{is still Too hi} \]

---

Considering a AHAM 1700 heat sink

Surface area = \[ 9.124 + 1.0(24)(2) + .316 \]

\[ = 57.74 \text{ in}^2 / \text{in} \]

\[ P_1 = 9.124 + 1.31(2) = 11.744 \]

\[ P_2 = 57.74 - 11.744 = 45.996 \]
Assume \( L = 6'' \)

\[ W = 1.0'' \quad D = 0.25'' \quad L = 6'' \]

\[ P_1 = \frac{L}{D} = \frac{6}{0.25} = 24 \quad P_2 = \frac{W}{D} = \frac{1}{0.25} = 4 \]

\[ F_{1-A} = (1 - 0.8) = -0.2 \quad C_L = 6'' \]

Assume \( L = 5'' \)

\[ P_1 = \frac{5}{0.25} = 20 \quad P_2 = 4 \quad F_{1-A} = 1 - 0.71 = -0.22 \]

Assuming one heat sink 5'' long

Three Trane per heat sink

\[ \Sigma Pd = 24 \times (3)(3.41) = 245.52 \]

\[ \Sigma Pd = 245.52 \]

\[ \text{If } L = 5'' \]

\[ 130^\circ F \]

\[ 140 \]

\[ 150 \]

\[ 180 \]

\[ 177 \]

\[ 72.53 \]

\[ 105.386 \]

\[ 143 \]

\[ 25.4 \]

\[ 242 \]

\[ \therefore \text{This is } 177^\circ F \]

Which is excessive

Assume \( L = 6'' \)

\[ \text{If } L = 6'' \]

\[ 140 \]

\[ 150 \]

\[ 170 \]

\[ 125.5 \]

\[ 164 \]

\[ 247 \]
Assume \( L = 8'' \)

\[
\begin{align*}
P_1 &= \frac{L}{24} = 32 \\
R_2 &= 4 \\
F_1 - A &= 1 - .81 = .19
\end{align*}
\]

<table>
<thead>
<tr>
<th>THI</th>
<th>SPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>112</td>
</tr>
<tr>
<td>140</td>
<td>128</td>
</tr>
<tr>
<td>150</td>
<td>207</td>
</tr>
<tr>
<td>155</td>
<td>232</td>
</tr>
<tr>
<td>160</td>
<td>258</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
L = 8'' & \\
F_1 &= 10 \\
R_2 &= 4 \\
F_1 - A &= 1 - .75 = .25
\end{align*}
\]

<table>
<thead>
<tr>
<th>THI</th>
<th>SPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>131</td>
</tr>
<tr>
<td>140</td>
<td>144</td>
</tr>
<tr>
<td>150</td>
<td>241</td>
</tr>
<tr>
<td>152</td>
<td>253</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
L = 10'' & \\
F_1 &= 12 \\
R_2 &= 4 \\
F_1 - A &= .13
\end{align*}
\]

\[
\begin{align*}
L = 12'' & \\
F_1 &= 12 \\
R_2 &= 4 \\
F_1 - A &= .13
\end{align*}
\]

\[
\begin{align*}
\text{THI} & \quad \text{SPD} = 245.52 \\
130 & \quad 149.97 \\
140 & \quad 211.56 \\
145 & \quad 243.79 \\
147.2 & \quad 251.25 \\
145.3 & \quad 245.7
\end{align*}
\]

\[\text{THI} = 145.3'']
\[ T = T_{HS} + Q \frac{\Delta R}{R} = 135.3 + 24 (1.0 + 5)(0.8) = 210.1^\circ F \ (99^\circ C) \]

**VII**  
20 HP 240V

\[ I_{RMS}/Leq = 51.9 \text{ amps} \]

Assuming Two Triacs per Leg:

Type sc106 - \[ I_{RMS}/Triac = 26 \text{ amps} \]

\[ P_d/Triac = 26 \text{ watts} \quad T_{max} = 115^\circ C \]

\[ R_2-C = 1.10 \text{ Ohms} \quad R_C-HS = 0.4 \text{ Ohms} \]

\[ T_{HS}(max) = T_2 - 0.82R = 105^\circ C - 26(1.1 + 0.4) \]

(Temperature)

\[ = 66.0^\circ C \ (150.8^\circ F) \]

1st Assume 1720 HS. \( L = 12.0'' \)

\[ SPd = 26(6)(3.41) = 531.96 \]

\[ \begin{array}{cc}
L = 12'' & SPd \\
160 & 345 \\
180 & 491 \\
\end{array} \quad \text{and is inaccurate} \]

Assume Two Triacs per heat sink

Type 1720 - \( L = 6'' \quad F_m = 0.2 \)

\[ R_i = \frac{6}{24} = 24 \quad SPd = 26(6)(3.41) = 177.3 \]
\[ T_{2} = \text{From} + \pm Q = 153.5 + 26(24)(44) \]
\[ = 219.02 \, ^\circ F \] (104°C)

- Could use three #1700 - #45 -
  Two 5c265 closer per line - each
  6" long

- Box size - 18 x 15 x 4" - 13

\[ \frac{5}{8} \]
\[ \frac{18}{12} \rightarrow 1 \]

II Continued - 50 HP - 480 volt

\[ \text{SPd} = 245.52 \text{ @ 3 times per hrs.} \]

Consider a \[ \sqrt{305} \text{ #41 (1220)} \]
\[ A_{/in} = 8 \times 2 - 6.07 = 76.33 \]
\[ P_{1} = 7.00 + 3.12(2) = 13.24 \]
\[ P_{2} = 73.33 - 13.24 = 60.09 \]

\[ L = 8" = \frac{1}{2} \]
\[ R_1 = \frac{L}{D} = \frac{8}{.5} = 16, \quad R_2 = \frac{L}{D} = \frac{2}{.5} = 4 \]

\[ F_{1-2} = 1 - .05 = .95 \]

\[ \text{This} \quad \text{SPD} = 245.52 \]

\[
\begin{array}{cc}
L = 8'' & 130 \\
# & 140 \\
& 145 \\
& 143 \\
& 144 \\
& 143.5 \\
\end{array}
\]

\[
\begin{array}{cc}
155 & 219 \\
259.8 & 279 \\
246 & 242 \\
\end{array}
\]

\[ T_2 = 144^\circ F + 24'(10+5)(6) \]

\[ = 208.8^\circ F (98.2^\circ C) \]

\[ = \text{Use The } 5305 \text{ HS - } 8'' \text{ Long} \]

Three Triacs per HS -

\[ \text{Continued - } 30 \text{ HP, 240V} \]

\[ P \text{Triac} = 26 \text{ watts} \]

Two Triacs per Leg - 5305

\[ \text{This} \text{ mot} = .150.8^\circ F \]

Assume all Triacs one one HS.

\[ \text{SPo} = 26(6)(3.41) = 531.96 \]

Assume \( L = 15'' \) Type 5305 HS.
\[ R_1 = \frac{L}{D} = \frac{15}{.5} = 30 \quad R_2 = \frac{L}{1 - .12} = 4 \]

\[ F_{1-4} = 1 - .12 = .88 \]

\[
\begin{array}{cc}
\text{THS} & \text{EPD} = 531.96 \\
130 & 248 \\
140 & 350 \\
150 & 459 \\
160 & 571 \\
170 & 514 \\
180 & 520 \\
190 & 525 \\
200 & 531.5 \\
210 & \\
\end{array}
\]

Assume \( L = 16'' \)

\[
\begin{array}{cc}
\text{THS} & \text{EPD} \\
145 & 448 \\
150 & 509 \\
152 & 533.8 \\
151 & 521.4 \\
\end{array}
\]

\[ T_d = THS + \frac{\Delta T}{R} = 152 + 26(11 + 4) \text{ (degree) } \]

\[ = 2222^\circ F \text{ (105.7\%)} \text{ (see pg 116)} \]

\[
\text{VIII} \quad 30\text{HP} = 440\text{ Volt}
\]

\[ \text{Emt/Leg} = 38.9 \text{ amperes} \]

\[ \text{Assume Two Triacs per Leg} \]

\[ \text{Items/Triac} = 19.5 \text{ - amperes} \quad T64001 \]
Tydon dissipates 16 watts at 19.5 I rms. \( T_2 \max = 110^\circ \text{C} \)

\[ T_\text{hr max} = T_y - Q \text{ER} = 100^\circ \text{C} - 16(10 + .5) \]

\[ = 76^\circ \text{C} (168.8^\circ \text{F}) \]

If all the Tracer one on one heat sink - \( \varepsilon PD = 16(6) = 96 \) watts which is a bit high for one HS.

Therefore assume 3 Tracer per heat sink - \( \varepsilon PD = 16(3) \varepsilon = 48 \)

\[ \varepsilon PD = 96(3.41) = 327.36 \]

Assume 5305 HS - 5" Long

\[ R_i = \frac{L}{\varepsilon} = \frac{5}{.5} = 16 \]

\[ R_2 = 4 \]

\[ \therefore R_{i-A} = 1 - .75 = .25 \]

| \( L=5" \) | 150 | 155.79
| 140 | 2.19 |
| 150 | 3.87 |
| 160 | 3.58 |
| 157 | 3.86 |
| 156 | 3.25 |
| 155.8 | 3.22 |

\[ T_y = T_{hr} + \varepsilon QR = 155.8 + 16(10 + .5) \varepsilon = 199^\circ \text{F} \]
If \( L = 2'' \) Type 5300-

\[
P_1 = \frac{2}{.5} = 4, \quad P_0 = 4
\]

\[
F_{1-x} = 1 - .74 = .26
\]

<table>
<thead>
<tr>
<th>THS</th>
<th>Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>155°F</td>
<td>290.3</td>
</tr>
<tr>
<td>160</td>
<td>322.7</td>
</tr>
<tr>
<td>162</td>
<td>337</td>
</tr>
<tr>
<td>161</td>
<td>329</td>
</tr>
<tr>
<td>160.5</td>
<td>328</td>
</tr>
<tr>
<td>160.7</td>
<td>327</td>
</tr>
</tbody>
</table>

\[
T_f = THS + Q\triangle R = 160.7 + 16(10 + .5)(.2)
\]
\[
= 203.9°F (95.5°C)
\]

IX

304 MP - 240 VDC

\[
I_{rms/leg} = 77.8 \text{ amps}
\]

Assuming two TRIACs per leg Type

T84210 (Rated at 60 amps each)

\[
I_{rms/ TRIAC} = 38.4 \text{ amps}
\]

\[
P_d/\text{TRIAC} = 42 \text{ watts} \quad T_{max} = 115°C
\]

\[
T_{max} = T_f - Q\triangle R = 100 - 42(1.4 + .2)
\]

allow

where \( R_{2-C} = .4 \text{ ohm/m} \quad R_{CHS} = .2 \text{ ohm/m} \)

\[
T_{max} = 74.8°C (168.6°F)
\]
If all the triacs are mounted on one HS - EPD = 42(6)(0.4) = 85.52 W

This is excessive for the 530° heat sink (REF 20WPE24010511)

- Assume there are three holes per heat sink
  EPD = 42 (3)(0.4) = 429.66

Assume 530° HS, L = 9"

\[ P_1 = \frac{L}{D} = \frac{9}{.5} = 18 \] 

\[ F_1 - a = 1.0 - .76 = .24 \]

\[ T_{\text{hs}} \]

<table>
<thead>
<tr>
<th>H.S.</th>
<th>Temp.</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>530°</td>
<td>164.6</td>
<td>429.25</td>
</tr>
<tr>
<td>164</td>
<td>424</td>
<td></td>
</tr>
<tr>
<td>164.6</td>
<td>429.25</td>
<td></td>
</tr>
</tbody>
</table>

\[ T_2 = T_{\text{hs}} + Q \times R = 164.6 + 42(0.4 + 3)(10) \]

\[ = 209.96 \text{ (98.9°C)} \]
VII  Continued - 20HP 240V

I_{rms}/leg = 51.9 amperes

Using Two SC265 Treats per leg

I_{rms}/Triac = 51.9 / 2 = 26 amperes

PD/Triac = 26 watts.

This max = 2 \sqrt{2} R

allow

R_{g-c} = 110 \, \Omega, \quad R_{c-hi} = 440 \, \Omega

This max = 105 - 26 (110 + 4)

= 66^\circ C (150.6^\circ C)

Assume Three Triacs per each 500W Type heat sink

\[ \Sigma P_{dl} = 26(3)(3.4) = 265.98 \]

Assume \[ L = 6'' \]

\[ R_i = \frac{6}{12} = 0.5 \]

\[ R_\phi = 4 \]

\[ F_{1-4} = 1 - 0.23 = 0.77 \]

\[ \begin{array}{c|c|c}
\text{THS} & \Sigma P_{dl} & \text{THS}>150^\circ F \\
140 & 175 & \text{and in} \\
150 & 229 & \\
155 & 257 & \\
\end{array} \]
Assume \( T = 0 \)°C

\[ F = 14 = -2 \]

\[ \text{Test} \]

\[ \text{PPD} = 265.5 \text{°F} \]

\[ L = 8 \]°C

<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td></td>
</tr>
<tr>
<td>147</td>
<td></td>
</tr>
</tbody>
</table>

\[ 219.5 \cdot 49 \]

\[ 266.5 \]

\[ = 197.5 \text{°F} \]

\[ T_2 = T_{HS} + Q_{ER} = 147 + 26(1.5) \times 49 \]

\[ = 217.5 \text{°F} (102.5 \text{°C}) \]
Revised Thermal Analysis - Ivec Controller

Assuming 80°F cooling air and ambient temperatures

1 HP - 240 volts

I rms \( \sqrt{2} \) = 2.96 amps

Assuming SC240 Triac (C.E.)

From C.E. data sheet - @ I rms = 2.96 a, Power Dissipation = 3.9 watts

\( T_j \) max = 100°C, \( R_{j-c} \) = 20°C

REF C.E. - \( R_c-HS \) = 2.5°C/m with 3 mil mica washer & silicone grease.

\( T_j - T_{HS} = Q \times R_{HS} \)

\( T_{HS} = T_j - Q \times R_{HS} \)

\( T_{HS, max} = 100°C - 3.9w (2.2 + 2.5) \)

= 81.67°C (179°F)\( (max) \)

\[ \Delta T \]

\( fluid-HS \) = 179 - 80 = 99°F
If the cho-therm heat sink elastomer is used:

\[ \text{Area} = \left( \frac{\pi}{2} \right) \left( \frac{1.55}{2} \right) \left( \frac{1}{2} \right) - \frac{\pi}{4} (1.55)^2 \left( \frac{2}{2} \right) \]

\[ = 0.737 \text{ in}^2 \]

\[ k_{\text{mica}} = 0.34 \text{ kT/m/\text{hr} } \cdot 45^2 \cdot 0.01 \text{ in} \]

\[ R = \frac{L}{k A} = \frac{0.005 (144) (3.44)}{(12)(-3.4)(737)(10)} = 0.27 \text{ \textdegree C/watt} \]

\[ k_{\text{silicone grease}} = 0.455 \text{ kT/m} \]

\[ \frac{\text{in}^2}{\text{hr} \cdot 45^2 \cdot 0.01 \text{ in}} \]

@ 0.005 mil the interface

\[ R_{\text{silicone}} = \frac{0.005 (144) (3.44)}{(12)(-3.4)(0.455)(737)(10)} \times 2 = 0.68 \text{ \textdegree C/watt} \]

\[ 2(R_{\text{mica}} + R_{\text{silicone}}) = 0.27 + 0.68 = 0.95 \text{ \textdegree C/watt} \]
\[ k \text{ CHO thermal} = 2.5 \frac{\text{BTU}}{\text{ft}^2 \cdot \text{hr} \cdot \text{R}} \]

\[ R = \frac{L}{kA} = \frac{0.020 (144) (3.41)}{12 (2.5) (232) A} = 1.97^\circ \text{C/watt} \]

If two aluminum interface are considered. Then \( \Sigma R = -247 + 2(6) = 1.45^\circ \text{C/watt} \)

- The TO-3 Heat sink To Thin Case Thermal Resistance will be in the range of 0.95^\circ \text{C/watt} to 2.5^\circ \text{C/watt}.

Again - if a .002 inch mica washer is assumed plus two greased joints @ .4^\circ \text{C/watt} (Ref 62) then -

\[ \Sigma R_{\text{mica}} = -4(2) + .27 = 1.07^\circ \text{C/watt} \]

Assume the diodes are mounted in the center of the 6"x8"x4" housing 16 gauge steel \( t = .060 \) in thick.

\[ k = 27 \frac{\text{BTU}}{\text{ft}^2 \cdot \text{hr} \cdot ^\circ \text{F}} \]
Total Power = 3.9 x 8 = 11.7 W
\[ h_c = 0.29 \left( \frac{A_t}{T} \right)^{1/4} \]

Assume \( AT = 99^\circ F \)
\[ h_c = 0.29 \left( \frac{99}{60} \right)^{1/4} = 1.01 \text{ Btu} \text{ hr-ft}^{-2} \text{ F}^{-1} \]
\[ h_r = 0.1714 \times 10^{-2} \text{ Fe Fa} \left[ \frac{T_1 + \frac{T_2}{100}}{100} \right] \left[ \frac{T_1}{100} \right] \left( \frac{T_2}{100} \right)^{-1} \left( \frac{54}{39} \right)^{3} \]
\[ F_e = 10 \quad F_c = 0.8 \]
\[ T_1 = 60^\circ F = 541.12^\circ F \quad T_2 = 179^\circ F (639^\circ F) \]
\[ h_r = -0.1714 \times 10^{-2} (0.8) \left[ \frac{540}{639} + 6.39 \right] \left[ \frac{5.40}{6.39} \right] \]
\[ h_r = 1.13 \]
\[ h_T = h_r + h_c = 1.01 + 1.13 = 2.14 \text{ Btu} \text{ hr-ft}^{-2} \text{ F}^{-1} \]
\[ Q = h_c A T \]
\[ 11.7 (3.41) = 214 \times (8 \times 6) \text{ AT F} \]
\[ Q = \frac{3.14}{4} \]
\[ \Delta T^\circ F = 55.90^\circ F \]
\[ m = \sqrt{\frac{h_c}{K_a}} = \sqrt{\frac{(0.14) (6) (114)}{(273 \times 0.06 \times 6) (10)}} = 3.98 \]
\[ Q = K \cdot m \cdot A \cdot \theta_0 \cdot \tanh(c \cdot t_b) \]

\[ \frac{11.2}{2} \left(3.41\right) = 27 \left(3.78\right) \left(6\right) \left(0.06\right) \theta_0 \cdot \tanh \left[ \frac{27 \times 3.41}{144} \right] \]

\[ \theta_0 = 125^\circ F \quad (C = T_x - 14) \]

\[ T_x = L = T_f + \frac{T_x - T_0 - 14}{\cos h_m L} \]

\[ T_x = 14 \left(85^\circ F\right) = \frac{0.495 \left(85^\circ F\right)}{\cos h_m \left(3.9\right)} \left(\frac{1}{2}\right) \]

\[ T_{fluid} = 80^\circ F \quad - \quad T_{case} = 80 + 65^\circ F \quad m_c = 145^\circ F \left(60^\circ R\right) \]

\[ h_r = \left(1.714 \times 10^{-2}\right) \left(2\right) \left[5.40 + 6.05\right] \left[5.40 + 6.05\right] \]

\[ h_r = 1.03 \]

\[ h_T = 1.03 + 0.904 = 1.934 \]

\[ m = \sqrt{\frac{h_c}{54}} = \sqrt{\frac{1.934 \left(6\right) \left(144\right)}{\left(2\right) \left(27\right) \left(0.06\right) \left(6\right)}} = 3.78 \]

\[ \theta = \frac{11.2}{3.41} = \left(27\right) \left(3.78\right) \left(6\right) \left(0.06\right) \theta_0 \cdot \tanh \left[ 3.78^\circ C \right] \]
\[ \theta_c = 91.7^\circ F \]

\[ T + h_0 + 91.7^\circ F = 171.8^\circ F \]

Which is acceptable.

If the radiation & convection inside the box is considered and that \( R_c + h_0 = 1.00 \text{ cm} \)

Then \[ T_{\text{max}} = T_2 - Q_{\text{ER}} \]

\[ = 100^\circ C - 3.9(\omega_2 + \omega_3) \]

\[ = 66.74^\circ C \ (158^\circ F) \]

\[ \Delta T_{\text{flow}} - \theta = 158 - 10 = 108^\circ F \text{ max.} \]

Assume \( \Delta T = 70^\circ F \)

\[ h_c = \frac{-29}{\sqrt{20}} (\frac{\Delta T}{5}) = 0.29 \left( \frac{20}{5} \right) \]

\[ h_r = 1714 \times 10^{-2} \left( \frac{5.4 + 6.13}{5.4 + 6.13} \right) \]

\[ = 1.04 \]

Assume \( h_f = (h_r + h_c) \times 0.5 = \frac{1.04 + 0.29}{2} \times 0.5 \)

\[ = 0.575 \]

\[ m = \frac{\sqrt{h_c + h_r}}{h_f} = \sqrt{\frac{0.925 \times 0.5}{(2)(27)(0.6)(6)}} \]

\[ = 4.62 \times 10^{-5} \]

\[ \omega = k \mu m A \theta_{\text{es}} \text{Tanh}(m \ell) \]
\[
\begin{align*}
\frac{11.2 (3.41)}{2} &= 27 (4.6215) (0.0666) \theta_0 \tan \beta (4.0457) \\
\theta_0 &= 65.0 \\
T_x &= \frac{64}{\cos \theta (4.6215 \times \frac{1}{2})} = 27.79 = \frac{\theta_0}{90}
\end{align*}
\]

\[
\theta_{\text{mean}} = \frac{65 + 27.79}{2} = 48.3
\]

\[
h_{\text{mean}} = \frac{-29}{(4.6215 \times 0.2)} = -0.46
\]

\[
T_f = 500^\circ F = 540^\circ R
\]

\[
T_{\text{HR}} = \theta_0 + 41.5C = 121.2^\circ F (550^\circ R)
\]

\[
h_r = -17.4 \times 10^{-3} C \left[ T_{HR} + 540 \right] \left[ T_{HR}^2 + 540^2 \right] = 0.987
\]

\[
h_T = (h_r + h_c) C = (0.46 + 0.96) \times 1.8 = 2.75
\]

\[
\phi = h_c \Delta T
\]

\[
\frac{11.9 (3.41)}{2} = (2.75) (6 \times 10^4) \Delta T
\]

\[
\Delta T = 44.06^\circ F
\]

\[
\phi = \frac{\sqrt{(2.75) (6) (144)}}{12 (27) (0.0666)} = 1.77
\]

\[
\mu = 4.517
\]

\[
\frac{11.2 (3.41)}{2} = 27 (4.517) (0.0666) \theta_0 \tan \beta (4.0457
\]

\[
\theta_0 = 72.28
\]

\[
\phi = \frac{72.28}{(144)} = 0.50
\]
$\Theta_{\text{mean}} = \frac{22.28 + 80.6}{2} = 51.44$

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<thead>
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</thead>
<tbody>
<tr>
<td></td>
<td>$h_e$</td>
<td>$\Theta_0$</td>
<td>$\Theta_1$</td>
<td>$\Theta_2$</td>
</tr>
<tr>
<td>70°F</td>
<td>2.85</td>
<td>69.27</td>
<td>48</td>
<td>41.19</td>
</tr>
<tr>
<td>48°F</td>
<td>2.75</td>
<td>72.27</td>
<td>51.44</td>
<td>44.26</td>
</tr>
<tr>
<td>45°F</td>
<td>2.71</td>
<td>72.98</td>
<td>52.04</td>
<td>44.92</td>
</tr>
</tbody>
</table>

$h_c = 0.29 \sqrt{\frac{4.5^2 (10)}{4}} = 0.8312$

$\Theta_f = 100°F (54.29), \Theta_{30} = (\Theta_0 + \Theta_f) = 54.29°F$

$h_r = (1714 \times 10^2) \times 10 \left[5.45 + 5.40 \left(\frac{7.45 + 5.40}{\Theta_f}ight)ight]$

$h_r = 0.978$

$h_{ef1} = (-0.312 + 0.978)(15) = 2.71$

$\frac{11.7 (3.41)}{2} = 27 (4.410) (0.646) \Theta_0 \tan \Theta_0 (4.410) (0.646)$

$m = \sqrt{2.71 \times 10^2} = 4.410$

$\Theta_0 = 72.98$

$\Theta_0 = \frac{72.98}{\Theta_0 \left[\frac{4.410 \times 4}{10} \right]} = 31.21$

$11.9 (3.41) = 2.71 (0.646) \Delta T$

$\Delta T = 44.92$
\[ T_0 = 78^\circ F \]

\[ T_f = T_{hr} + Q_{SR} \]

\[ T_f = 100 + 25 + 3.9(0.2 + 25) \text{ (C-lit)} \]

\[ = 115.99^\circ F \text{ (C-15.5^\circ C)} \]

\[ T_f = 100^\circ C \text{ (212^\circ F)} \]

\[ T_{hr} = 179^\circ F \]

\[ T_{fluid\ max} = 179 - 73 = 106^\circ F \]

\[ \text{C Rch} = 25 \]

\[ R_{ch} \text{ @ 1.2} = 164^\circ F \]

\[ T_{fluid\ max} = 164 - 73 = 115^\circ F \]

\[ \text{C Rch} = 1.2 \text{ ft} \]

**5 HP, 480 Volts**

Use sc1245: \[ R_2 - c = 1.65^\circ C/\text{watt} \]

\[ T_{m} = 74 \text{ a} \quad P_d = 9 \text{ watts/1 ft} \]

\[ T_f \text{ max} = 100^\circ C \]

\[ T_{hr} \text{ max} = T_f - Q_{SR} \]

\[ = 100^\circ C - 9(165 + 25) \]

\[ = 62.65^\circ C \text{ (144.8^\circ F)} \]

\[ \text{C Rch} = 25 \]

(Non-isolated)
The max. = 100°C - 9(165 + 1.2)
    = 74.2°C (165.3°F)
@ Rms= 1.2%

If first assume that
θo = 144.8 - 80 = 64.8°F max.

From graph - (νT approx.)
@ L = 8" hε = 1.01

hT = 0.1214 x 10^{-2}(9)[5.4 + 6.05²] [5.4² + 6.05²]
    = 1.16

hT = 1.01 + 1.16 = 2.17

Q = hε A ∆T

A = \frac{Q}{hε} = \frac{9(2)(2.41)}{6.54 \text{ ft}² \ (94.3 \text{ in.})}

= 5 in. high need a 11.7\" width
   (Too much)

= need a heat sink, finished

Assume IERE section E103 - 1.5\" long
C = 21.0

From "graph" hε = 154

Considering convection only -
(9)(3.41) = 154 (24\%) (2) (64.8)

1 - 1.045
E260 series cont compared
To E103 - check it out

Assume 5" long heat unit
(section E103)

Fin Height = 1.68", Spacing = .66
W = 1.68", L = 5.0", D = .66

\[ R_2 = \frac{W}{D} = \frac{1.68}{.66} = 2.54 \]

\[ R_4 = \frac{4}{D} = \frac{4}{.66} = 6.03 \]

From Chart \( F_a = 1/.6 = .4 \)

C Total = 18.6°F/hr - 3" section -
5" section = \( \frac{5}{5} \) CHF = 106°F/hr

\[ AT = 2R = 2.71m \times 1.106 = 29 \, ^\circ\text{C} (89 \, ^\circ\text{F}) \]

\( T_{smk} = 80 + 52 = 132^\circ \text{F} \quad -174^\circ \text{F max allowable} \)

Consider E240 section:

L = 5", TR = 4.6°F/m

\[ R_2 = \frac{4.6}{.3} = 15.36 \, \text{m} \]

\[ AT_{smk-air} = 2R = 2 \times (1.76) = 7.02^\circ \text{C} (15.5^\circ \text{F}) \]

\( T_{smk} = 70^\circ \text{F} + 134 = 204^\circ \text{F} \quad \text{which is} \]

 promising.
- Assume $S''$ Long Section $E_{103}$

$$C = 24.0 \text{ in}^3 \text{ in} \quad \& \quad \Delta T = 52$$

$$h_c = 0.29 \left[ \frac{\Delta T}{2} \right]^{1/4} = 0.29 \left[ \frac{52}{2} \right]^{1/4}$$

$$h_c = 0.969 \quad A = 24.0 \text{ in}^2 = 100 \text{ in}^2$$

$$T_{in} = 130^\circ \text{F} (752^\circ \text{R}) \quad T_f = 60^\circ \text{F} (540^\circ \text{R})$$

$$h_r = 0.1714 \times 10^{-2} \text{ FA} \leq \left[ \frac{T_i + T_s}{1.8} \right] \left[ \frac{(T_1 - T_s)}{10^2} \right] \left[ \frac{1}{10^2} \right]$$

$$h_r = 0.1714 \times 10^{-2} \text{ FA} \leq \left[ \frac{T_i + T_s}{1.8} \right] \left[ \frac{(T_1 - T_s)}{10^2} \right] \left[ \frac{1}{10^2} \right]$$

$$h_r = 0.448 \text{ at } FA = 0.0 \quad h_r = 0.12 \text{ at } FA = 1.0$$

$$A = 3.937 \text{ (6)} + 150 \text{ (8)} \left( \frac{2}{3} \right) = 34.69 \text{ in}^2$$

$$A_{FA = 4} = (1.5) \text{ CG} \left( \frac{1}{2} \right) = 6.25 \text{ in}^2$$

$$Q = \left( \frac{3}{4} A \right) (\Delta T)$$

$$Q (3.41) = \left[ 8.25 \left( \frac{4.44}{3} \right) + 3.469 \left( \frac{1}{2} \right) + 0.969 \right] \left( \frac{1}{4} \right)$$

$$\Delta T = 69^\circ \text{F}$$

$$T_{in} = 60 + 69 = 149^\circ \text{F}$$

If a 6" length is used -

$$A_{FA = 1.0} = 3.937 \text{ (6)} + 150 \text{ (6)} \left( \frac{2}{3} \right) = 41.62 \text{ in}^2$$

$$A = 1,500 \text{ in}^2 = 90 \text{ in}^2$$
\[ T_0 = \frac{90(0.448) + 41.62(0.12) + 0.339(0.6)}{2} \]

\[ h_c = -0.29 \left[ \frac{4 \cdot 7}{2} \right]^{1/4} = 0.29 \left[ \frac{55}{6} \right]^{1/4} \]

\[ = 0.939 \]

\[ \Delta T = 59.7^\circ F \]

\[ T_{HV} = 60 + 59.7^\circ F = 119.7^\circ F \]

No acceptable - (44.4°F max allowable)

\[ R = \frac{\Delta T}{c} = \frac{59.7}{1.23} = 48.1^\circ F/\text{hour} \]

3" section - \( R = 15^\circ F/\text{hr} \)

6" section - \( R = 15 \left( \frac{2}{6} \right) = 5^\circ F/\text{hour} \)

\[ \text{6" Long 100 section is } \]

Requird - [have a 5°F to 25°F max]

III 5 HP, 240 v/175

14.8 amps per leg - use 50 A

\[ R_y = 1.6^\circ F/\text{hr} \]

\[ P_d = 20 \text{ watts/leg} \]

\[ T_d \text{ max} = 115^\circ C \]

Assuming \( P_{max} = 3.5^\circ C/\text{watt} \)

\[ T_{hr} \text{ max} = T_d - 2ER \]

\[ = 115^\circ C - 20(16 + 2.5) = 33^\circ C (41.4) \]
II Cont. - if assume 1.6" long

E 103 section

\[ \Delta T = 25^\circ C \left( 85^\circ F \right) \]

\[ h_c = -29 \left( \frac{\Delta T}{L} \right) = -29 \left( \frac{45 \times 12}{126} \right) \]

\[ h_c = 1.23 \frac{BTU}{\text{hr-ft}^2} \]

\[ h_r = 0.1714 \times 10^{-2} \left( 9 \right) \left[ 3.4 1 + 5.85 \right] \left[ 5.4^2 + 5.4^2 + 5.4^2 \right] \]

\[ = 1.10 \]

\[ h_r = 0.44 \quad F_c = 4 \]

\[ A_F = 1 = 3.937 \left( 1.6 \right) + 150 \left( 1.6 \right) \left( 2 \right) = 11.099 \text{ in} \]

\[ A_F = 4 = 15 \left( 1.6 \right) \left( 10 \right) = 24 \text{ in}^2 \]

\[ \left[ \frac{3.41}{C} \right] = \left[ 1.23 \left( 24 \right) \left( 1.6 \right) + 44 \left( 24 \right) + 11.099 \left( 10 \right) \right] \frac{A_F}{14} \]

\[ \Delta T ^\circ F = 63 ^\circ F \left( 35.1 ^\circ C \right) \]

'I ERC has 30^\circ C or 84.4^\circ F rise'

If consider the back side of the fn

\[ A_F = 1.0 = 3.937 \left( 1.6 \right) \left( 2 \right) + 150 \left( 1.6 \right) \left( 2 \right) = 17.40 \]

\[ \left[ \frac{3.41}{C} \right] = \left[ 1.23 \left( 24 \right) \left( 1.6 \right) + 44 \left( 24 \right) + 17.4 \left( 1.10 \right) \right] \frac{A_F}{14} \]

\[ \Delta T = 57 ^\circ F - \left( 3146 ^\circ C \cdot \text{KNO} \right) \]

Which is very close to the I ERC data point
II Continued - (5 HP, 480V)

E102 Section 150/1400

Order: \( P \) \( W \) \( = \) 9 \text{ watts} \n
Assume: \( R \) \( = \) 180 \text{ o.m} \n
\( R_{12} = -4 \text{ o.m} \) \( T_{2 \text{ max}} = 100 \text{ o.c} \)

\[ T_{\text{max}} = T_2 - Q \times R \]

\[ = 100^\circ - 9 \times [1.5 + 4.5] \]

\[ = 80.2^\circ \text{ (176.4 o.c)} \]

\( AT = 176.4 - 10 = 96.36^\circ \text{ F} \)

Assume all driers on one heat

\( \sin \beta = \frac{L}{5^\prime} \) \( T = 60^\circ \text{ F} \)

\( P_1 = 3.937 + 16 \theta (2) = 7.313 \)

\( P_2 = 16 \theta (2) + 150 (\theta) = 15.38 \)

\( R = \text{Chapman} - D = 0.64 \)

\( K_1 = 1.500 \) \( L = 5^\prime \)

\( R_0 = \frac{W}{I} = \frac{155}{6.6} = 2.32 \)

\( F_{12} = 0.55 \)

\( R_1 = \frac{L}{D} = \frac{5}{6.6} = 0.76 \)

\( F_N = 1 - F_{12} = 1 - 0.55 = 0.45 \)

\( A_{\delta c} = 24 - 3.937 = 20.062 \text{ inches} \)
Using the Calculation Program

\[ T_{0.1}^\circ F = 50.0 \]

\[ \begin{array}{c|c}
120^\circ F & 45.0 \\
150^\circ F & 95.0 \\
160^\circ F & 105 \\
155^\circ F & 97.8 \\
158^\circ F & 94.8 \\
152^\circ F & 93.0 \\
151^\circ F & 91.4 \\
\end{array} \]

\[ T_w = T_{0.1} + 9(1.6 + 0.1) = 157.5 + 9(2.0) = 167^\circ F (86^\circ C) \]

If a 6 inch long E103 is used-

\[ R_2 = \frac{14}{0.6} = 23.3 \quad R_1 = \frac{6}{-61} = 0.09 \]

\[ F_m = 1 - 0.09 = 0.91 \]

\[ \begin{array}{c|c}
T_{0.1}^\circ F & 5 \\\n120 & 53.62 \\
130 & 65.97 \\
140 & 87.16 \\
145 & 96.05 \\
142 & 90.07 \\
143 & 92.46 \\
\end{array} \]

\[ T_w = 143 + 9(2.3) = 178.6^\circ F (81^\circ C) \]

---

Use the 6" E103 section

Isolated diodes, one per line.

Three diodes mounted on the top 6" x 6" x 4" case.
If an $Re_{cr} = 120$ is assumed

This max. $= 118^\circ-20 (125+4) = 72^\circ$ (Isolated case)

$\Delta T = T_{hs} - T_f = 128.2 - 80 = 48.2^\circ F$

If one considers the isolated case, $Re = 175^\circ/c/m$, $Re_{hs} = 4.4^2/c/m$

This max. $= 118^\circ-20 (175+4) = 72^\circ$ (Isolated case)

$\Delta T_{hs-f} = 161.6 - 60 = 101.6^\circ F$

4) Consider non isolated case

$\Delta T_{hs-f} = 58.2^\circ F$

$TR = (E 103 \text{ section}) = 10^\circ/c/m $ in $y$

Assume $R''$ Leng: $Pd = 60$ in.

$\Delta T = \theta R = 60 (10) = 60^\circ C$ (108 $^\circ F$)

excessive

$h_c = -29 \left( \frac{\Delta T}{L} \right)^{1/4} = -29 \left( \frac{58}{60} \right)^{1/4} = .89$

$h_r = -45 \text{  at } FA = -4 \quad h_r = 112 \text{  at } FA = 10$

$AFA = 1.2 = 3.9 R (2) + 150 P (3) (2) = 55.5 \text{ in.}^2$

$AFA = -4 = 15 (P) (1) = 120$
\[(60) (3.41) = \left(100 (0.15) + 55.5 (1.10) + 24 (0.03) \right) \frac{\Delta T}{144} \]

\[\Delta T^\circ F = 106^\circ F \text{ which is} \]

\[\text{Excessive} \quad (138^\circ F \text{ max allowable}) \]

\[\Delta T^\circ F = 186^\circ F = 106 + 80^\circ F \]

If Two droper per line are used-

\[\Delta T^\circ F = 100.6 - 80 = 100.6^\circ F \]

and the 8" long E103 section is acceptable.

Checking this \( \Delta T = 100.6^\circ F \)

\[h_c = \frac{-29 (\Delta T)^{\frac{1}{4}}}{h_c = \frac{1.03 \text{ atm} \text{ hr} \cdot \text{ ft}^2}{h_c = \frac{1.03 \text{ atm} \text{ hr} \cdot \text{ ft}^2}} \]

\[T_{f} = 105^\circ F (\text{max}) \quad \text{as } \Delta T = 100.6^\circ F \]

\[h_r = \frac{1714 \cdot 10^{-2} \cdot (2.4) (2.3) (5.4 \cdot 6.4)^2}{15.4 + 6.4} \approx 1.521 \text{ \text{CF = .4}} \]

\[(60) (3.41) = \left(100 (0.15) + 55.5 (1.10) + 24 (0.03) \right) \frac{\Delta T}{144} \]

\[\Delta T^\circ F = 90^\circ F \]

\[T_{f} = 80 + 90 = 170^\circ F \] \(160.6^\circ F \text{ max} \) \( (\text{not used}) \text{ allowable} \)
- 

Long section would theoretically be long enough but there is insufficient room for 6 diodes (i.e., \( L = 1502 \times 6 = 9012 \) in).

Consider non-isolated case. This max = 138°F (\( \Delta T = 58.3°F \)) 20 watts one diode per leg - one heat sink per diode.

\[
\begin{align*}
\frac{hC}{L} & = 29 \left( \frac{\Delta T}{L} \right)^{1/4} = 29 \left( \frac{58.3}{L} \right)^{1/4} \approx 1.05 \\
AFA & = 0.75 \left( C_y \right) + 1.50 \left( C_y \right) = 2.25 \text{ in}^2 \\
AFA & = 4 = 1.5 \left( C_y \right) (2) = 6 \text{ in}^2
\end{align*}
\]

\[
\left( 20 \right) \left( 3.44 \right) = \left[ 60 \left( 40 \right) + 22.75 \left( 1.5 \right) + 1.05 \left( 2.5 \right) \left( 4 \right) \right] \frac{\Delta T}{L}^{1/4}
\]

\[\Delta T_{of} = 61.4°F\]

\[T_{HS} = 60 + 61.4°F = 121.4°F \text{ (5/13 135.5°F max)}\]

Which means that three heat sinks, one per diode, 4" long sections of E103 - use 4" x 4" case (based on: \( R_c \text{m}^2 = 1.2^2 0.04 \text{ ft}^2 \))
5 HP 240 volt case — (non-isolated)

a) Two non-isolated diode per line — One 8" long E103 section, case 6 x 8 x 4, HS mounted on the side (will not fit)

b) One non-isolated diode per line — Three 4" long E103 sections, one per diode, case 6 x 8 x 6 all mounted on the front panel of 6 x 8 x 4 case with two mounted on the front panel and one on the side

5 HP 240 volt — isolated case

From before — (P514)

2) One diode per line, $R_y-c = 1.25$

$R_{ch} = 0.4$ $Th_{max} = 161.6^\circ F$

$AT = 161.6 - 80 = 81.6^\circ F$

Assume E103 section — $L = 8''$

$T_f = 80^\circ F$ (540 OR) $Th = 161.6 (701 OR)$
\[ h_R = 0.1714 \times 10^{-2} \times (4.8) \times (3 \times \sqrt{5} \times 2) \]
\[ h_R = 0.599 \text{ e } F_a = 0.4 \]
\[ h_R = 1.50 \text{ e } F_a = 1.0 \]
\[ h_c = -29 \left( \frac{A_1}{2} \right) = -29 \left[ \frac{0.6}{0.03} \right]^{1/2} = -965 \]
\[ A = 555 \text{ m}^2 \text{ e } A_F = 100 \text{ m}^2 \]
\[ (60)(3.41) = \left[ \frac{1}{2} \times (5.5) + 0.599(6.0) + 0.965 \times (0.6) \right] \frac{\Delta T}{144} \]
\[ \Delta T^\circ F = 86.5^\circ F \]
\[ T_m = 80 + 86.5 = 166.5^\circ F \text{ e } \Delta R = -4.0^\circ \text{C} \]

Which is very close to being accepted.

\[ c) \left\{ \begin{array}{l}
\text{5 HP 240 volt - (Isolated case)} \\
\text{one diode per line, EL103 section}
\end{array} \right. \]

8" inchers long, all choker on one section - 10 x 6 x 8 x 4 - 4" on the side

\[ d) \text{5 HP 240 volt - Non Isolated case} \]

**forced convection**

Assume \( Q = 90 \text{ cfm} \)

\[ V = \frac{Q}{A} = \frac{90 (144)}{6(80)} = 480 \text{ fps} \]
Section Length = 1507 x 3 = 45”
Assume a 5” long section
Three diodes on one section

\[ \Delta T^\circ F \text{ rise} = \frac{Q_i}{\eta \cdot \rho c_p} = \frac{60 \text{ W} \cdot (2.24 \text{ g/cm}^3)}{(20)(60)(24)(914.1)} \]

\[ \Delta T^\circ F \text{ rise} = 10.6^\circ F \]

With 50°F inlet air - \( T_{out} = 90.6^\circ F \)

\[ T_{mean} = 85^\circ F \]

\[ T_{max} = 91.4^\circ F \]

\[ R_{ch} = 2.5 \text{ °C/cm} \]

\[ R_{ch} = 12.0 \text{ °C/m} \]

Taking the latter assumption - i.e.

\[ R_{ch} = 1.2 \text{ °C/m} \]

Assume \( T_{th} = 138.2^\circ F \)

\[ T_{mean} = \frac{138.2 + 85}{2} = 116.5^\circ F \]

\[ \mu = 0.47, \quad k = 0.0161, \quad \frac{c_p \mu}{k} = 0.724 \]

\[ \eta = 0.695 \]

\[ N_{2} = \frac{V_{0} P}{(4)(60)(57)(0.695)} \]

\[ N_{2} = \frac{0.047}{12 (0.347)} \]

\[ = 17.24 \]
The flow is laminar.

\[ \frac{h_{c}}{C} = \frac{0.0161}{C_{2}} (664) \left( \frac{1}{3} \right) \left( \frac{1.374}{C} \right)^{1/2} \]

\[ \frac{h_{c}}{C} = 3.02 \text{ atm/hr-ft}^{2} \text{ of} \]

\[ Q = h_{c} A \Delta t \text{ Assuming section} \]

\[ E102 \quad C = 300 \text{ in}^{2} / \text{ft} \]

\[ 6 \times (3.44) = 3.02 \left( \frac{10^{-2}}{C} \right) (5) \left( \frac{1}{1.44} \right) \]

\[ \Delta T_{F} = 50 \text{ oF} \]

\[ T_{hr} = 55 + 50.2 = 135 \text{ oF} \]

which is acceptable.

\[ \text{Could use one for } \frac{1}{2} \text{ ft long} \]

\[ E102 \text{ section, non isolated deck} \]

\[ \text{One deck per line, all decks} \]

\[ \text{on one section} \text{ - case size} \]

\[ 6 \times 6 \times 6 \text{ in} \]

- [Diagram]

Original page is of poor quality.
Continued -

SHP 240 volts, I = 148 amperes

ISE 3.0, isolated, Rg - c = 1.25

Pd / leg = 90 watts, Assume Rm = 0.4

Tmax = 122°C

= 115°C - 20°C(1.25 + 4) = 72°C

One diode per line

Assume all diodes on a 6'' line

Long section

EQ = 60(3.41) = 204.6

<table>
<thead>
<tr>
<th>Thr</th>
<th>EQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>105</td>
</tr>
<tr>
<td>170</td>
<td>143</td>
</tr>
<tr>
<td>180</td>
<td>163</td>
</tr>
<tr>
<td>190</td>
<td>184</td>
</tr>
<tr>
<td>200</td>
<td>205</td>
</tr>
</tbody>
</table>

Assume 8'' Long section (5103)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>150</td>
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<tr>
<td>160</td>
<td>158</td>
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<td>170</td>
<td>183</td>
</tr>
<tr>
<td>180</td>
<td>208</td>
</tr>
</tbody>
</table>

Assume l = 1.5 Long section (5103)

One diode per section

EQ = 20(3.41) = 64.2

<table>
<thead>
<tr>
<th>Thr</th>
<th>EQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>16.4</td>
</tr>
<tr>
<td>150</td>
<td>32.7</td>
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<td>170</td>
<td>44.1</td>
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<td>210</td>
<td>70.2</td>
</tr>
<tr>
<td>220</td>
<td>76.7</td>
</tr>
<tr>
<td>230</td>
<td>82.4</td>
</tr>
</tbody>
</table>
Assume \( L = 4" \) EL103 section

One diode per line -

\[
\begin{array}{c|c}
\text{\textdegree F} & \text{EQ} \\
120 & 37.8 \\
140 & 61.5 \\
145 & 62.8 \\
148 & 64 \\
149 & 65.3 \\
146 & 69.0 \\
145.5 & 68.1 \\
\end{array}
\]

\( T_{\text{EQ}} = 145.5 \text{\degree F} \)

\( T_{2} = 145.5 + 20(0.15)(1.5) \)

\( = 228.9 \text{\degree F (106\textdegree C)} \)

Assume \( L = 8" \) EL103 section

One diode per line -

\[
\begin{array}{c|c}
\text{\textdegree F} & \text{EQ} \\
150 & 58.09 \\
160 & 68.4 \\
\end{array}
\]

\( T_{2} = 160 + 20(0.15)(1.5) \)

\( = 232.4 \text{\degree F (117\textdegree C)} \)

\( \therefore \text{Line 4" Long EL103 sections} \)

One diode per line. (Simplified)

(4" x 8" x 4" box)

\( \)

Original page is of poor quality.
IV. 10 HP - 480 Volts

1) 13 amps per leg - 5.250

\[ P_d = 17.0 \text{ watts per leg} \]

Could use the same option as for the 5 HP - 240 volt condition.

V. 10 HP - 240 Volts

a) \[ I_{\text{rms}} = 25.9 \text{ amps per leg} \]

Using \( S_C \ 265 \) \[ P_d = 26 \text{ watts} \]

\[ R_{2-L} = 0.95 \text{oHm/m} \]

(Then isolated \( \text{ choke} \))

\[ T(H) = T_j - Q \text{ ER} \]

Assume \( R_{\text{ch}} = 12 \text{oHm} \)

\[ T(H) = 115^\circ C - 26 (20 + 10) \]

\[ = 59.1^\circ C (13^\circ F) \]

\[ AT \text{ inlet-outer} = \frac{Q_{\text{inlet}}}{Q_{\text{outlet}}} = \frac{26(240/20)(60/20140)}{26(240/20)(60/2140)} \]

\[ = 13.8^\circ F \]

\[ T_{\text{mean}} = \frac{80 + 93.6}{2} = 86.9^\circ F \] (sec 11-24)
\[
\begin{align*}
\text{Total Temp} &= \frac{126.4 + 86.9}{2} = 113.5 \degree F \\
\text{Kain} &= 0.160, \quad \text{L} = 0.045 \\
P &= 0.695, \quad \text{Nkr} = -7 \\
V &= 480 \text{ rpm} \quad \text{Assume } L = 6'' \\
\text{Mr} &= \frac{(480)(600)(6)(0.0695)}{12(0.045)} = 21,522 \\
\bar{h}c &= \frac{(0.160)(-664) (21,522)^{1/2} (27.5) (0.045)}{6} \\
\bar{h}c &= 2.77 \quad \text{Assume } E = 102, \quad C = 50.7 \\
Q &= \bar{h}c A \Delta T \\
26(3)(3.41) &= 0.77 (3.41)(6) \frac{\Delta T \degree F}{144} \\
\Delta T \degree F &= 59.5 \degree F \\
\therefore \quad \text{Ths} &= 46.9 + 59.5 = 146.4 \degree F \\
\text{which is acceptable considering radiation was neglected.} \\
\text{use } 6'' \text{ long } E102 \text{ section, } 3 \text{ diode per section, long case size } 4'' \times 6'' \times 6''
b) 10 HP - 240 VAC

\[ I_{in} = 259 \text{ a, per leg} \]

Using sc 265 \[ P_d = 26 \text{ w/m}^2/\text{deg} \]

Isolated case - \[ P_{d-c} = 1.1 \text{ w/m}^2 \]

\[ P_{d-m} = .4 \text{ w/m}^2 \]

\[ T_{sc(men)} = T_d - Q_{ER} \]

\[ = 115^\circ C - 26(11+y) = 76^\circ C (16\%) \]

\[ AT_{HS - fluid} = 165.8^\circ F - 11 = 154.8^\circ F \]

If an IEC 2103 section is assumed - one 3" section per diode -

\[ h_c = 0.29 \left( \frac{4}{L} \right) = 0.29 \left( \frac{0.8}{3} \right) \]

\[ = 1.26 \text{ BTU} \]

\[ T_{a} = 65^\circ F (18.3^\circ C) \]

\[ T_{hs} = 165.8^\circ F (62.6^\circ C) \]

\[ h_r = 1.214 \times 10^{-2} \text{ (.9)} \left[ 5.4 + 6.29 \left[ 5.4 + 6.29 \right] \right] \]

\[ h_r = 1.239 \text{ (\text{FA}=1.0)} \]

\[ h_r = 0.986 \text{ (\text{FA}=0.8)} \]

\[ A_{FA}=1.0 = 1.659 \left( \frac{2}{0.6} \right) = 2.7 \]

\[ A_{FA}=0.8 = 2.410 \left( \frac{2}{0.6} \right) = 6.6 \]

\[ 26(3.41) = [1.986(30.1) + 0.986(45)] + 24(3.26) \left[ \frac{AT}{100} \right] \]

\[ AT = 96.9^\circ F \text{ (43^\circ F to 66.1)} \]
If a 4" long section is assumed...
Continued -

10 HP - 240 volts - 25 & a/leg
Use SC 265 - isolated
Rd - 26 watt/leg

$P_2 = 0.10 \text{ ohm} \quad R_{eq} = 0.4 \text{ ohm}$

$T_{hs} = T_f - 622^\circ$

$= 115^\circ - 26 (0.10 + 0.0) = 76^\circ$ (162°F)

If a 1/103 section 5" long
is assumed - one isolated disk
per section

$E_2 = 26 (3.4) = 88.26$

$T_{hs} \quad E_2$

\[ \begin{array}{c|c|c}
160 & 105 & 160 \\
155 & 97.82 & 155 \\
150 & 90.84 & 150 \\
149 & 84.32 & 149 \\
\end{array} \]

\[
\sqrt{160} \quad 105 = T_{hs} = 149^\circ F
\]

$L = 50"$

$T_2 = 149 + 26 (1.5) (1.0)$

$= 215^\circ F (104^\circ C)$

If a 1/103 section 4" long
is assumed - one isolated side
per section

$T_{hs} \quad E_2$

\[ \begin{array}{c|c|c}
160 & 82.50 & T_{hs} = 161^\circ F \\
161 & 85.85 & L = 40$
\]

$T_f = 161 + 26 (25) (1.0)$

$= 281.8^\circ F (110.5^\circ C)$
Checking the drop down the 5" long fin - 

\[ \Delta T = 149 - 80 = 69^\circ F \]

\[ Q = \text{26 watts} \]

\[ \Delta T = 24 - 0.937 = 20.063 \text{ in} \times 5^\circ \text{m} \]

\[ 26 (3.41) = \text{left} \left( \frac{20.063 (0)}{144} \right) \]

\[ \text{left} = 1.84 \text{ ft/m/s/hr ft}^2 \text{ of} \]

\[ Q = 15 \text{ m A}_c_0 \text{ So Tanh (m/2)} \]

\[ M = \sqrt{\frac{h}{\text{S} A_c_0}} = \sqrt{\frac{(1.84) (444) (20.063)}{(20) (1.572) (12)}} = 1.80 \]

\[ 26 (3.41) = 90 (1.10) (1.517) (80) \text{Tanh} \left[ \frac{1.84 (25)}{144} \right] \]

\[ \text{So} = 144.9 \text{ (close to 149°F)} \]

Drop down the length of the fin - 

\[ T_x = L = T_f + T_x = 0 - T_f \]

\[ \text{Cosh ml} \]

\[ T_x = L - T_f = \frac{149^\circ F}{\text{Cosh ml}} = \frac{149}{\text{Cos ml Cos}[149/ml]} \]

\[ = 139^\circ F \]

\[ \text{I have a 10°F drop down the length of the fin:} \]
- Use the 5" long E103 section one isolated choke per section.

Box size: 10" x 4" x 20 HP - 480 volts

\[\text{I}_{\text{rms}}/\text{leg} = 25.9 \text{ amps} \]

Use SC 265, PD = 26 watts per leg.

\[\text{I}_{\text{rms}} = \] 

1.2. The same as the 10 HP-240 volt condition - use the same configuration.

2. Consider that two chokes per leg, isolated SC 265, one used in parallel - \(\text{I}_{\text{rms}}/\text{chokes} = 25.9 \text{ amps}\)

It could use the same cooling configuration as in VII except have two chokes per HS.
VIII 30 HP - 440 Volts

\[ I_{\text{rms}} = 35.9 \text{ Amps} \sqrt{\frac{1}{2}} \text{ per leg} \]

\[ = \text{ Use a SC-265 - 100 Amps} \]

\[ = 44 \text{ Watts} \quad T_2 = 115^\circ \text{C max} \]

\[ P_2 = 110^\circ \text{C max} \quad \text{Assume} \quad R_{\text{ehs}} = 4^\circ \text{C} \]

\[ T_{\text{max}} = T_2 - QER \]

\[ = 115^\circ \text{C} - 35.9 \left[ \frac{1}{1+4} \right] = 56.65^\circ \text{C} \]

\[ = (133.9^\circ \text{C}) \]

Assume E103 section \( \ell = 6" \)

\[ \Sigma Q = 44(3.4) = 150.4 \]

\[ T_{\text{ms}} \]

\[ 120 \quad 53.63 \]

\[ 150 \quad 105 \]

\[ 160 \quad 123 \]

\[ 170 \quad 143 \]

\[ 180 \quad 163 \]

\[ 190 \quad 153 \]

\[ 200 \quad 151 \]

b) Assume an E103 section and two Drooler per leg

\[ I_e = 28.9/2 = 19.45 \text{ Amps} \]

Assume SC-260, isolated, Type diode
c) Assume two diodes per line

\[ V = 19.45 \text{ volts} \quad P_d = 18 \text{ watts/diode} \]

\[ T_{\text{max}} = T_2 - \frac{12 E R}{3} \]

\[ = 115^\circ C - \frac{12 (125 + 4)}{3} = 74^\circ C \]

\[ = (165)^\circ C \]

Assume E103 section 5" long

\[ E_0 = 2 \times (2) \times (3.4) = 143.22 \]

<table>
<thead>
<tr>
<th>( T_{\text{max}} )</th>
<th>( E_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>45.8</td>
</tr>
<tr>
<td>160</td>
<td>105</td>
</tr>
<tr>
<td>170</td>
<td>122</td>
</tr>
<tr>
<td>180</td>
<td>139.37</td>
</tr>
<tr>
<td>195</td>
<td>143.7</td>
</tr>
<tr>
<td>192</td>
<td>143.4</td>
</tr>
</tbody>
</table>

\[ T_{\text{max}} = 165^\circ F \text{ which is still excessive} \]

Assume E103 section 6" long

\[ T_{\text{max}} = \frac{E_0}{3} \]

<table>
<thead>
<tr>
<th>( T_{\text{max}} )</th>
<th>( E_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>53.63</td>
</tr>
<tr>
<td>170</td>
<td>143.37</td>
</tr>
</tbody>
</table>

\[ T_{\text{max}} = 170^\circ F \text{ still excessive} \]

Assume two diodes per line of the SC 265 type - Check

\[ \sqrt{V} = 19.45 \text{ volts} \quad P_d = 18 \text{ watts/diode} \]

\[ T_{\text{max}} = T_2 - \frac{12 E R}{3} \]

\[ = 115^\circ C - 12 \times (1.1 + 4) = 84^\circ C \]

\[ = (100.4^\circ C) \]
Assume E103 section 5' Long

\[ P_d = 12\text{ HP} = 36 \text{ watts} \]

\[ E = 36 \text{ (amps)} = (122.76) \]

<table>
<thead>
<tr>
<th>Temperature</th>
<th>( E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>45.5</td>
</tr>
<tr>
<td>160</td>
<td>105</td>
</tr>
<tr>
<td>170</td>
<td>122.5</td>
</tr>
</tbody>
</table>

\[ T_{ef} = 170^\circ F + 17\left(\frac{193}{14}\right) \]

\[ = 215.6^\circ F (102^\circ C) \]

- Could use two diodes per line. Isolated Type SC 265, E103 section - 5' Long. Box 500 \( 38 \times 10^\text{44} \) Three heat sinks needed.

IX 30 HP - 240 volt condition -

\[ I_{rms}/leg = \frac{72.8}{2} = 36.4 \text{ amps} \]

a) Assume Three SC 265 diodes per line - \( I_{rms}/diode = 25.9 \text{ A} \)

\[ P_d / \text{diode} = 26.0 \text{ watts} \]

\[ T_2 \text{ max} = 110^\circ C \]

\[ T_{ef} = 115 - 26\left(\frac{1.1 + 4}{3}\right) = 76^\circ C (168.4^\circ F) \]
Assume 6" Long E10.3 section

\[ 20 = 26.0(3)(3.14) = 265.98 \]

<table>
<thead>
<tr>
<th>Temp</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>280°F</td>
<td>206</td>
</tr>
<tr>
<td>220</td>
<td>251</td>
</tr>
<tr>
<td>225</td>
<td>263</td>
</tr>
</tbody>
</table>

\[ \text{THS} > 225°F \text{ which is excessive; } 168°F \text{ max allowable.} \]

Consider E320 section

\[ P_1 = 4.50 + 1.40(2) = 7.3 \]
\[ P_2 = 1.40(18) = 25.2 \]

\[ W = 1.40 \quad L = 6" \quad D = 0.30 \]
\[ P_1 = \frac{W}{D} = \frac{6}{0.3} = 20 \]
\[ P_2 = \frac{W}{D} = \frac{1.4}{0.3} = 4.6 \]

\[ F_{th2} = -0.8 \]
\[ F_n = 1 - F_{th2} = 1 - 0.8 = 0.2 \]
\[ A_{th} = 32.3 - 4.5 = 27.8 \]

Assume \[ L = 6" \]
\[ \varepsilon = 20 = 265.98 \]

<table>
<thead>
<tr>
<th>THS</th>
<th>[\varepsilon]</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>168.23</td>
</tr>
<tr>
<td>180</td>
<td>191</td>
</tr>
<tr>
<td>190</td>
<td>216</td>
</tr>
<tr>
<td>200</td>
<td>241</td>
</tr>
<tr>
<td>210</td>
<td>267.7</td>
</tr>
</tbody>
</table>

\[ \text{THS} = 210°F \]

Which is excessive.
If four diodes per line are considered - E300, Type HS-

Irms/diode = 77.8 = 19.45 amp -

Pd/diode = 78 watts/diode

Ths max = 72 - 0.7R

= 115 - 100(1 + 0.01) = 156°F

EQ = 18°C • (3.4) = 245.5°F

Ths = 202°F

Assume a E360 section - 6" long -

4.5 x 625, isolated, diodes per line -

Pd = 6.500 + 1.6(C0) = 9.2

Pd = 16(C0) = 32

k = 1.6, L = 6.0, D = .5

Rf = \frac{L}{D} = \frac{6.0}{0.4} = 15

R2 = \frac{L}{D} = \frac{1.6}{0.4} = 4

-- F10 = .76
\[ F_{n} = F_{a} = 1 - F_{10} = 1 - .765 = .235 \]

\[ \Delta f/jin = 43.2 - 6.5 = 36.7 \]

\[ \Delta Q = \Delta f/J(3.41) = 245.72 \]

\[
\begin{array}{|c|c|}
\hline
THS & EQ \\
\hline
150 & 170.88 \\
160 & 1291.71 \\
170 & 233.14 \\
190 & 299.5 \\
180 & 266.00 \\
179 & 262.66 \\
179.1 & 264.3 \\
173.7 & 245.17 \\
\hline
\end{array}
\]

\[ = THS = 173.7^\circ F \]

\[ T_2 = 174 + 14(45)/15 = 222.8^\circ F (105^\circ C) \]

- Could use four SC265 diode per line, isolated. Three E360 sections each 6" long - 4 diodes ea.

Box size 15" x 15" x 4"

\underline{Considered Forced Convection}

- 20 HP 240 volt

a) Assume two diodes per leg, isolated SC265 Type I rms/leg = 31.9 a

\[ Pd/diode @ 2 per leg = 26 \text{ watts} \]

\[ @ 26 \text{ amperes per diode} \]
Consider isolated stud type-

SC265 - Pry-c = .95°c/m
Rchv = .4°c/m

THSmx = Tg - OER
= 115 - 26(C.95+2) = 79.9°
(175°F)

Total power demand = 26(6)(3.4)
= 531.96 Btu/hr

ΔT°F = .286 k(26/90) = 6°F
(2° 90 C.068)

Rise is negligible

Tmax = Tg + 176 = 131°F

K = .0165, L = .0672, μ = .048,
HPR = .7, Tg = 88°F

Trying E101 section L = 5"
Pf10%= 26.9 in.²/in

Using the TI-59 program-
<table>
<thead>
<tr>
<th>Diameter</th>
<th>E (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>147.28</td>
</tr>
<tr>
<td>170</td>
<td>245.28</td>
</tr>
<tr>
<td>190</td>
<td>302</td>
</tr>
<tr>
<td>250</td>
<td>477</td>
</tr>
<tr>
<td>260</td>
<td>500</td>
</tr>
<tr>
<td>280</td>
<td>556</td>
</tr>
</tbody>
</table>

The THS is above 270°F which is not acceptable.

If $L = 10''$, $E 101$ section

<table>
<thead>
<tr>
<th>Diameter</th>
<th>E (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>262</td>
</tr>
<tr>
<td>200</td>
<td>467</td>
</tr>
<tr>
<td>205</td>
<td>567</td>
</tr>
<tr>
<td>215</td>
<td>527</td>
</tr>
</tbody>
</table>

The THS is above 215°F, not acceptable.

Trying a $E 122$ section

$L = 6''$, $P = 35.7$ in.$^2$/in

<table>
<thead>
<tr>
<th>Diameter</th>
<th>E (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>298</td>
</tr>
<tr>
<td>200</td>
<td>520</td>
</tr>
<tr>
<td>210</td>
<td>565</td>
</tr>
<tr>
<td>205</td>
<td>540</td>
</tr>
<tr>
<td>202</td>
<td>529</td>
</tr>
<tr>
<td>203</td>
<td>524</td>
</tr>
</tbody>
</table>

The THS @ 205°F is still not acceptable.

Trying a $E 122$ section

$L = 8''$, $E 202$ section

The THS is above 187°F and is still not acceptable.
Trying a E102 section - 10" long

\[ \text{This is the section we would need} \]

\[
\begin{array}{c|c|c}
\text{Voltage} & \text{Current} & \text{Note} \\
\hline
150 & 355 & \text{A 10" long E102 section} \\
150 & 555 & \\
175 & 529 & \\
176 & 534 & \\
\end{array}
\]

Six diodes on the section.

Trying a E613 section

\[ L = 6" \quad P_4 = 613 \]

\[
\begin{array}{c|c|c}
\text{Voltage} & \text{Current} & \text{Note} \\
\hline
150 & 472 & \text{This is 150°} \\
160 & 531 & \quad T_4 = 150 + 26(-95+4)(4) \\
155 & 507 & = 221°F(105°c) \\
157 & 521 & \\
158 & 528 & \\
\end{array}
\]

If the RCA type is considered - one per leg-

\[ T \approx 8411 \]

\[ I_{\text{emr}} = \frac{D_0(748)}{173(240)(0.8)(0.8)} = 51.9 \text{ amps} \]

\[ P_d = E I = 15 \times 519 = 77.85 \text{ watts} \]

Assume \( T_{\text{max}} = 150°c \)

\[ P_{g-c} = -38 \text{°c/m} \quad P_{\text{cm}} = -4 \text{°c/m} \]
\[ T_{\text{max}} = \frac{T_1 - Q \cdot \eta}{R} \]
\[ = 150 - 72 \cdot 5 (35 + 4) = 91.6 \degree C \]

Assume all the diodes are mounted on one heat sink.

**Total Dissipation:** 72.85 (2) (3.41)
\[ = 796.41 \text{ BTU/hr} \]

Assuming a 6013 section \( L = 6 \)°

<table>
<thead>
<tr>
<th>THS</th>
<th>180</th>
<th>190</th>
<th>200</th>
<th>195</th>
<th>196</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS</td>
<td>674</td>
<td>754</td>
<td>825</td>
<td>785</td>
<td>796</td>
</tr>
</tbody>
</table>

\( \sqrt{\text{L}} \) 

- \( \text{THS is 196} \degree F \) and the H.S. 15° marginally accepted

**II**

- 30 HP 480 V 1011T

2) **Assume one diode per 265 per**

\[ \text{Leg 1, Pd/leg = 44 watts} \]

\[ \text{Isolated stud} \]

\[ T_{\text{max}} = \frac{T_1 - Q \cdot \eta}{R} \]
\[ = 115 - 44 (-95 + 4) = 85.6 \degree C \]

(132.9°F)
\[ z = 44(3)(3.41) = 450.12 \]

Assume \( E613 \) section \( L = 6'' \)

\[
\begin{array}{c|c}
P_{f/\text{in}^2} & 612.3 \\
\hline
\text{THS} & Q \\
260 & 120 \\
472 & 150 \\
437 & 145 \\
451 & 147 \\
\end{array}
\]

\[ \text{THS} = 147^\circ F \]

Which is unacceptable

Assume \( E615 \), \( L = 6'' \) section

\[
\begin{array}{c|c}
P_{f/\text{in}^2} & 71.4 \\
\hline
\text{THS} & Q \\
469 & 140 \\
437 & 135 \\
443 & 137 \\
442 & 137.5 \\
451.7 & 138.9 \\
\end{array}
\]

\[ \text{THS} = 138^\circ F \]

\[ \text{Would not be acceptable} \]

Box size \( 4'' \times 4'' \times 6'' \)

Assume \( E615 '' \) section - 7'' Long

\[
\begin{array}{c|c}
\text{THS} & Q \\
128^\circ F & 328 \\
130 & 317 \\
138 & 487 \\
135 & 461 \\
134 & 452 \\
\end{array}
\]

\[ \text{THS} = 134^\circ F \]

Which is still unacceptable

Original page is of poor quality.
Assume EGT section -

\[ L = 6'' \]
\[ P_{in} = 17.9 \]

\[
\begin{array}{c|c}
& \Delta \\
I_{in} & 2.0 \\
130 & 492 \\
135 & 499 \\
132 & 461 \\
131.5 & 456 \\
130.5 & 472 \\
\end{array}
\]

\[ T_{HS} = 130^\circ F \]

6'' long section

one diode per leg SCA65 stud 10#

One heat sink

1004 SDC - 8'' x 10'' x 6''
1) 1 HP 240/20 volt

Diode 6YF-5C 240 one leg

Heat Sink - none

Case Size = 6 x 8 x 4" = 6.40
Cover = \( \frac{7.76}{2} \)

\( \text{H.S.} = \# 6 \text{ holes} - \text{Total of 6 req'd for the transition and two for mountings} \)
3) 5 HP 240 Volt -
   One isolated SC 250 diode per leg - 2.79

   Three heat sinks required
   each - E103 - 4" long - 4.150
   Dia hole per sink
   Box size - 8" x 8" x 4 = 7.48
   Cover = 1.10
   Total = 8.58

   Need three clearance holes - 1.25 dia ea in the box

4) 10 HP 440 Volt - (SC250 isolated too)
   Same as 5 HP 240 volt case
   Except diode cost - 3.16/leg

5) 10 HP 240 Volt
   SC 265 - TO-3 isolated - 4.24 ea
   One diode per leg
   Three heat sinks required
   Hi - HE103 - 5" long - 4" #150 dia hole
   Required
   Box size - 8" x 10" x 4" - 9.72
5) Continued

Covers -

Need Three 125 HP electric motor

6) 20 HP - 480V

Some or 10 HP & 240 volt

One check per leg isolated to 3-5%

7) 20 HP - 240 volts

a) Two 5C 265 diodes, isolated to 3 per leg

Diode cost - 4.24 x 0.8 = $4.19/leg

Three heat sinks, same or

Hd = 546 except - 6 ft. 150 dia.

b) Forced Convection

\[
\begin{align*}
\text{Fan cost} & \quad \text{Cost} \\
\text{Grille inlet} & \quad \text{Cost} \\
\text{Outlet} & \quad \text{Cost} \\
\text{Transformer slot} & \quad \text{Cost} \\
\text{Case side} & \quad \text{Cost}
\end{align*}
\]

Two diodes per leg
E613 Section - L = 6"
One section Reg'd - 4 cut outs for mounting & Three 1/4" dia. block holes

b) 30 HP - 440 volts
   Free convection -
   Two E613 Stud isolated tubes
   Per Line - 10 5.14 (2) = 10.28/Line

H.S. E103 - 5" long - Three Reg'd
   Six - 150 dia holes
   Box size 8" x 12" x 4" = 922
   Cover - 130
   (Six 1.25 Dia Cutouts)
   (In the Box)

b) Forced convection
   2 Fan cover
   H.S. E605 Section - L = 6"
   Four box cutouts - Three 1/4" dia holes
Re Run of The
Prior calculations considering
If max = 100°F

\[ T_{\text{max}} = 100^\circ F \]

\[ T_{\text{in}} = 60 \text{ °F} \]

\[ P = 2.9 \text{ °F/ft} \]

\[ T_{\text{final}} = 99.1^\circ C \] \(= 209^\circ F\)

Assume \( n = \) heat sink except the steel can.

Assume \( L = 4\)" (01) \( T_{\text{f}} = 100^\circ C \) (02)

\[ P_1 = 6.0\)" (03) \( P_2 = Fa = N = 6.0 \) (04)

\[ Fa = 1.0 \]

\[ Fn = 1.0 \) (05) \( Aff - inch = 6.0 \) (06)

\[ \Delta Q = 3.9 (3.41) \) (07) = 33.547

\[ \Delta Q \]

\[ \begin{array}{c|c|c}
\theta & Q & T_{\text{HS}} \\
\hline
120 & 10.31 & \ \\
140 & 22.47 & \ \\
150 & 29.013 & \ \\
160 & 36.033 & \ \\
170 & 43.51 & \ \\
180 & 51.63 & \\
\end{array} \]

\[ T_{\text{HS}} = 165^\circ F \]
\[ Q = \Delta m \Delta \theta \tan h (\Delta T) \]
\[ h_c = 1.08 \text{ (RCU12)} \]
\[ h_{REA} = 1.28 \]

\[ m = \sqrt{\frac{h_c}{\Delta T}} = \sqrt{\frac{0.367}{\frac{0.341}{0.2} \cdot 0.6 \cdot 0.6}} = 4.18 \]

\[ 3.9(3) \cdot \frac{0.341}{2} = 2.1 \cdot 0.186 \cdot 0.6 \cdot 0.6 \theta_0 \tan h \left[ \frac{4.186}{12} \right] \]

\[ \theta_0 = 79.83 \text{ °F} \]

\[ T_{in} = 100 + 79.83 = 179.83 \text{ °F} \]

Draw down the line:

\[ T(x) = T_0 - \frac{T_0 - T_{in}}{C_{in} h_m L} \]

\[ C_{in} h_m L \cos h \left[ \frac{4.186}{12} \right] = 27 \]

\[ T(x) = 179.83 - 13.26 \]

\[ D_{in} = 179.83 - 13.26 = 42.57 \]

\[ T_{in} \text{ mean} = \frac{179.83 + 133.26}{2} = 158.5 \text{ °F} \]

\[ \Delta T \text{ mean} = 5 \text{ °F} \]

\[ h_c = -29 \left( \frac{\Delta T}{L} \right)^{-25} = \left( \frac{58.5}{12} \right)^{\frac{1}{4}} \]

\[ 29 \approx 0.99 \]
\[ h_{n} = 1714 \times 10^{-2} (\beta) \left[ \frac{(T_{1} - 100)^{2} + (T_{2} - 100)^{2}}{100 + 100} \right] \]

\[ T_{1} = 100 \, ^{\circ}F = 560 \, ^{\circ}R \]

\[ T_{2} = 157.5 + 460 = 617.5 \, ^{\circ}R \]

\[ h_{n} = 1714 \times 10^{-2} (\beta) \left[ 5.6 + 6.185 \right] \left[ 5.6 + 6.185 \right] \]

\[ = 1.265 \]

\[ h_{T} = h_{n} + h_{c} = 1.265 + 1.265 = 2.530 \]

\[ Q = h_{T} \Delta T \]

\[ 0.9 (3) (3.41) = 2.19 \times 10^{-2} \left( \frac{10}{144} \right) \Delta T \]

\[ \Delta T = 51.59 \]

\[ \therefore \; T_{hr} = 100 + 51.59 = 151.59 \, ^{\circ}F \text{ (mean)} \]

\[ \therefore \; T_{\max} = 155.59 + \frac{32.56}{2} = 174.2 \, ^{\circ}F \]

Which is very close to the 178.43.

In a prior calculation:

\[ T_{\max} = 174.2 + 3.9 (0.4) (15) = 193.6 \, ^{\circ}F \]

Which is acceptable considering that radiation & convection inside the box value ignored.
II 5 HP, 240 volts
0) I rms / leg = 7.4 amps
Using - sc 245 Type - Pd/leg = 90 watts
\[ P_d = 1.74 \text{ watts} \]
Thermal \[ T_d = EQR = 100^\circ C - 9(1.1 + 4) \]
\[ = 80.2^\circ C (176.36^\circ F \text{ mot}) \]
One diode per line
Assume 1, E103 section - 6" long
all the diodes mounted on the heat sink
\[ \Sigma P_d = 9(3)(3.41) = 92.03 \]
For a E103 section - \( 100^\circ F = 1^{\circ} \)
\[ P_1 = 7.313, P_2 = 15.09, F_d = .41 \]
\[ A f / in = 20.062 \]
\[ T_{\text{hrs}} = 30 (92.03) \]

<table>
<thead>
<tr>
<th>Temp</th>
<th>120°F</th>
<th>130°F</th>
<th>140°F</th>
<th>150°F</th>
<th>160°F</th>
<th>170°F</th>
<th>165°F</th>
<th>( 160^\circ F )</th>
<th>161°F</th>
<th>160.5°F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.13</td>
<td>40.18</td>
<td>56.29</td>
<td>73.36</td>
<td>129.6</td>
<td>110.0</td>
<td>100.5</td>
<td>91.29</td>
<td>93.13</td>
<td>82.21</td>
</tr>
</tbody>
</table>

\[ T_f = T_{\text{hrs}} + 0.2^\circ F \]
\[ T_f = 160.5^\circ F + 9(2.3)(1.4) \]
\[ = 196.14^\circ F (91.69^\circ C) \]
If a E103 section is used -
3 choker pen section - L = 7"

<table>
<thead>
<tr>
<th>Thr</th>
<th>Eq (92.02)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>83.09</td>
</tr>
<tr>
<td>155</td>
<td>94.02</td>
</tr>
<tr>
<td>153</td>
<td>94.74</td>
</tr>
<tr>
<td>154</td>
<td>91.97</td>
</tr>
<tr>
<td>154.5</td>
<td>90.99</td>
</tr>
</tbody>
</table>

\[ T_2 = 154.5 + 9(2.0)(1.5) \]
\[ = 190.14^\circ F (71.5^\circ C) \]

If a E103 section is used -
3 choker pen section - L = 9"

<table>
<thead>
<tr>
<th>Thr</th>
<th>Eq (92.02)</th>
<th>Thr = 149°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>94.26</td>
<td></td>
</tr>
<tr>
<td>149</td>
<td>92.02</td>
<td></td>
</tr>
</tbody>
</table>

\[ T_2 = 149 + 9(2.0)(1.1) \]
\[ = 154.64^\circ F (73.6^\circ C) \]

- Use the 7" long E103 section - Conera

Box size 6" x 8" x 4"

III 5HP, 240V 60Hz

| a) Inmr/leg = 148 w - Pd/leg = 20.0 wcm |
| Diode Type - SC250 (To-3 isolated) |
| Rg-c = 175.0 ohm - Rem = 0.4 ohm |
| Ther mol = T2 - CER = 115°F - 20(1.25+y) |
| = 72°F (16.1°C) |

(Cont. page 47A)
5 HP 480 volt Continued

Trans/leg = 7.7; using on Sc 250 diode: pd/leg = 5.0 watts
Rp-c = 1.75 °C/watt - Rcm = .4°/W

Thr max = 115 °C - h(125+4) = 92.8°
(208.04°)

(a) Assume E103 section = 2" long (2 NW)

\[ T_{hr} \quad \Sigma Q = 8(3.44) = 27.21 \]

\[
\begin{align*}
15 & : 26.49 \\
14.5 & : 25.11 \\
14.7 & : 26.45 \\
14.8 & : 27.13 \\
14.1.2 & : 27.26
\end{align*}
\]

\[
T_d = 14.1.2 + h(2.15)(0.8) = 179.16 (221.25°)
\]

\[
\sum T = 3 \times E103 + 5 - 3.65 \left( \frac{2}{12} \right) (2) = 4.25
\]

Pox - # Covers = 7.26

3 Sc 250 (410v) = 3 x 3.14 = 9.48

\[
\frac{9.48}{33.25° \text{ margin}}
\]

(b) Assume one 4" S - E103 - 6" long
Sc 250 diode

\[ \Sigma pd = 8(3)(3.44) = 81.24 \]
<table>
<thead>
<tr>
<th>T/H5</th>
<th>SPD (ft/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>56.29</td>
</tr>
<tr>
<td>150</td>
<td>72.36</td>
</tr>
<tr>
<td>155</td>
<td>82.22</td>
</tr>
<tr>
<td>154</td>
<td>80.43</td>
</tr>
<tr>
<td>154.5</td>
<td>81.32</td>
</tr>
</tbody>
</table>

\[ T = 154.5 + 8(2.15) = 165.46 \]  
\[ T_{\text{margin}} = 115 - 85.25 = 29.75^\circ C \]

- Use this option because the smaller heat sink is required and the margin one greater (5)

1e.

a) SC 245 - \( T_{2 \text{reg}} = 3(2.94) = 8.82 \)
   
   Case 4 Couch
   
   \[ 145 - 19.65 \left( \frac{2}{12} \right) = \frac{1.83}{1.87^\circ C} \]

   \[ T_{2 \text{margin}} = 115 - 85.75 = 29.75^\circ C \]  

b) SC 250 - \( T_{2 \text{reg}} = 3(3.16) = 9.48 \)
   
   Case 4 Couch
   
   Heat sink \( - 3.65 \left( \frac{2}{12} \right) = \frac{1.83}{1.87^\circ C} \)

   \[ T_{2 \text{margin}} = 115 - 85.25 = 29.75^\circ C \]  

Because of the mounting considerations - go to a 7" long Mr.
\[ \Sigma Pd = P(C3)(3.41) = 12.84 \text{ E102-7} \]

\[ T_{ir} \quad \Sigma Q = 17.44 \]

\begin{tabular}{|l|l|}
\hline
140 & 64.40 \\
145 & 74.02 \\
150 & 83.89 \\
147.5 & 78.90 \\
148 & 79.91 \\
149 & 81.90 \\
\hline
\end{tabular}

\[ T_f = 149 + 8(2.15) = 179.96 \text{ F \(820\text{ C} \)} \]

\[ T_{wiring} = 115 - 62.2 = 32.8 \text{ \circ C margin} \]

\[ \text{Case (6 x 6 x 4) = 2.44} \]

\[ 1 - E102-7 (3.65 \text{ C/2}) = 2.13 \text{ \circ F/2} \]

Original page is of poor quality.
Assume 4" long E103 section

(One grade per 100 per leg)

\[ \frac{Pd}{Hs} = 20 \text{ (3.48) } = 6.2 \]

\[ \frac{THS}{2} (6.2) \]

- 140 39.54
- 160 64.28
- 162 66.84
- 163 67.19
- 163.2 67.4

Which is only marginally acceptable

Assume L = 4.5" long E103 section

\[ \frac{THS}{2} (6.2) \]

- 155 64.06
- 157 66.89
- 158 68.71

\[ T_d = 157 + 20(2.15) \text{ (113°C) } = 231.4 \text{ °F (113°C) } \]

Assume L = 5" long - E103, one grade per leg

\[ \frac{THS}{2} (6.2) \]

- 150 62.6
- 152 65.6
- \sqrt{152} 67.15
- \sqrt{152.5} 67.9
- \sqrt{153.5} 68.2

\[ T_d = 157 + 20(2.15) \text{ (113°C) } = 231.4 \text{ °F (113°C) } \]

\[ \text{Total margin } = 9.2^\circ C + 11(20) = 6.4^\circ C \]

\[ C \text{ Rchw } = -39 - T_d < 115^\circ C \text{ by } 6.4^\circ C \]

\[ C L = 5" - 170 \times \sqrt{2} \times 1 \times 2 = 9.2 + 13.3 = 11.01 \]

\[ H5 = \sqrt{2.65(3)} = 2.91 - 3 - 1.25(24) = 3 \times 2.74 = 1.37 = 27 \]
b) Considering a E 360 section:

\[ L = 8^\circ, \quad P_1 = 9.7, \quad P_2 = 52 \]

\[ F_n = 0.28, \quad A_{\text{flw}} = 86.2 \]

\[ T_h r \max = 161.6^\circ F \]

\[ \Sigma P_c d = 20 (3) = 60 \quad \text{watt} = 204.6 \]

\[
\begin{array}{c|c}
T_h r & E_0 = 204.6 \\
120 & 82.11 \\
140 & 115.8 \\
150 & 151.0 \\
160 & 188.2 \\
170 & 227.2 \\
180 & 211.0 \\
164.5 & 201.0 \\
\end{array}
\]

\[ T_h r = 164^\circ F \]

Which is excessive.

c) If two drocer per line one used:

\[ \frac{\text{Inwr}}{\text{chle}} = \frac{14.8}{2} = 7.4 \]

\[ \text{use} \quad S C \quad 2x5 \quad T_h r \max = 100^\circ F \]

\[ \Sigma P_c d = 1.2 \quad \text{watt} \quad P_2 = 180^\circ F \]

\[ T_h r \max = T_2 - Q_x R = 100^\circ F - 8.3 (184.2) \]

\[ = 81.74^\circ F \quad (179^\circ F) \]

Assume \[ E_360 \quad 15^\circ F \quad 8" \quad \text{long} - \text{one} \]

\[ \Sigma H_5 \quad p_c d = 1.2 (6) (3.41) = 169.82 \]

\[
\begin{array}{c|c}
T_h r & E_0 \\
150 & 151.15 \\
155 & 169.51 \\
\end{array}
\]

\[ T_h r = 155^\circ F \]

\[ T_2 = 155 + 8.3 (2.2) \]

\[ = 187^\circ F (184.2) \]
Cost Comparison

1) H5 3 - E103 - 5" Long - 3.65(\frac{5}{12}) = 4.56
   Box & Cover 8\times12\times4 = 7.72 + .38 = 8.10
   Diodes - 2 - S245 (24x2) = 3\times2.24 = \frac{7.07}{24.03}
   \frac{F_2 = 110.5\%}{24.03}

2) 1 - E360 - 7" Long - 6.80(\frac{7}{12}) = 4.20
   Box & Cover 8\times7\times4 = 7.48 + 1.10 = 8.58
   Diodes - 6 - S245 (24x2) = 6\times2.64 = \frac{15.84}{20.62}
   (one H5 - 6 diode)

3) Assume E360 H5 7" Long - (2 diodes/l ine)
   \frac{F_2 = 169.7\%}{one H5}
   \frac{\bar{F}}{150} = 184
   \frac{\bar{F}}{160} = 168.00
   \frac{\bar{F}}{161} = 171.2
   \frac{\bar{F}}{160.5} = 169.7
   \frac{F_2 = 169.7 + 8.3(2.2)C_0}{202.6\% (94.7\%)}

4) 1 - E360 - 7" Long 6.30(\frac{7}{12}) = 3.68
   Box & Cover - 8\times7\times4 = 7.58
   Diodes - 6.5 - S245 - 6\times2.64 = \frac{15.84}{28.10}
   (F_2 = 94.7\%)

5) Assume E360 H5 - L = 2.5" - Two diodes per line - SC 275 - Pd/diode = \frac{7.84}{2.5}
Pd/ H5 @ 2 diodes per H5 = 16.6 (56.6)
<table>
<thead>
<tr>
<th>Temperature</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>160°F</td>
<td>58.4</td>
</tr>
<tr>
<td>155°F</td>
<td>52.52</td>
</tr>
<tr>
<td>157°</td>
<td>54.8</td>
</tr>
<tr>
<td>158°</td>
<td>56.02</td>
</tr>
</tbody>
</table>

\[ T_{in} = 154°F \]
\[ T_{o} = 158°F \]
\[ T_{i} = 81.7°F \]

\[ T = 158 + \frac{525(220)}{12} = 191.2°F \]

3 - E360 - 2" long - 6.30 x 2 (3) = 3.15

Box - 6 x 1 x 4 of copper = 226

Dioder - 6 x 245 - 6 (0.64) = 15.74

\[ T_{i} = 81.7°F \]

\[ T_{i} = 86.25°F \]

---

The 3 - E103 heat sinks - one pen each 10250 clock in the least costly arrangement -

\[ Q = h c A \Delta T \]

\[ \Delta T = 154 - 10.0 = 144°F \]

\[ 20 (3.4) = h c \left( \frac{5}{(0.063)(54.9)} \right) \]

\[ h c = 1.813 \]

\[ \frac{1}{54} \]

\[ m = \sqrt{\frac{h c}{BA}} = \sqrt{(1.813)(20.063)(144)} = 1.788 \]

\[ \frac{1}{10(50)(1577)} \]

\[ Q_{u} = \frac{Q_{i}}{C_{u}} = \frac{54}{C_{u}} \frac{h c}{(1.788)(25)} = 50.4°F \]
There is a 4°F drop down the fin.

f) Assume one side of the pen line - so 260 isolated To-3. 

\[ V_2 - c = 125.5^\circ C / \text{watt} \]

\[ T_2 \text{ max } = 115^\circ C \]

From leg: 

\[ Pd \text{ leg pen diode } = 14 \text{ watts} \]

\[ T_2 \text{ min } = T_2 - 2QR = 115 - 14(0.55 + 4) \]

\[ = 92.2^\circ C (189.46^\circ F) \]

Assume 8" Long E103 section (Concrete):

\[ 3Pd = 14.0(3)(3.41) = 143.22 \]

\[ T_{445} \]

\[ 50 = 143.22 \]

150 93.85
160 116.76
170 140.72
171 143.18

\[ T_2 = 171^\circ F + 14(1.95) \times 10^6 = 220.14^\circ F (104^\circ C) \]

11°C mins

Assume 7" Long E103 section - one HR.

\[ T_{170} \]

\[ 30 = 143.02 \]

170 125
140 147.5
175 136.2
250 133.02

\[ T_2 = 178^\circ F + 14(1.95) \times 10^6 = 227.19^\circ F (104^\circ C) \]

7°C mins

ORIGINAL PAGE IS OF POOR QUALITY.
1) 7" Long E103, one 45-3-SC260 diode

1 E103 - 7" Long - 3.65 (2) = 2.13
1 box # cover 6" x 4" x 4" = 7.26
Three 6C260 diodes 3.67 x 3 = 11.01
\[ \text{Total} = 20.40 \]

2) Assume 2" Long E103 section

3. Heat sink, one SC260 diode per line -

\[ SPd = 14 (3.14) = 44.74 \]

\[ \text{THS} \]
\[ 150 \quad 28.49 \]
\[ 160 \quad 35.50 \]
\[ 170 \quad 42.83 \]
\[ 173 \quad 45.09 \]
\[ 174 \quad 45.11 \]
\[ 176 \quad 47.37 \]
\[ 176.5 \quad 47.76 \]

\[ EQ = 44.74 \]

\[ T_2 = 176.5 + 14 (3.14) \]

\[ T_5 = 225.64 (107.5) \]

- have a 2.50% margin

3 E103 - 2" Long - 3.65 (2) (3) = 1.82

1 box # cover 6" x 4" x 4" = 7.26

Three 6C260 diodes - 3.67 x 3 = 11.01
\[ \text{Total} = 20.09 \]
To obtain even # of cut in

The Extrusion - Assume L = 6.25"

\[ T_{HS} \]
\[ \theta = 149.32 \]
\[ 179 \]
\[ 170 \]
\[ 141.35 \]
\[ 140.55 \]

\[ T = 180^\circ F + 14(1.95)\theta = 229^\circ F \]
\[ Margin = 6^\circ F \]

\[ \begin{align*}
\left\{ \begin{array}{l}
1 - E103 \cdot 6.25 &= 3.65 \cdot \left( \frac{6.25}{12} \right) = 2.053 \\
1 \text{ box of Cu en (6x8x4)} &= 7.26 \\
3 \text{ SC260 diode} &= 3(3.67) = 11.01 \\
\end{array} \right.
\end{align*} \]
\[ \text{Total} = 30.32 \]

\[ \text{IV} = 10 \text{ HP} - 440 \text{ volts} \]

\[ \text{Current/leg} = 13 \text{ amps} \]

\[ \text{With an SC260 diode} - \text{Pd/diode} = 12 \text{ wa} \]

\[ R_0 = 1.55^\circ C/\text{watt} \]

\[ E\text{Pd} = 12(3)(3.41) = 122.76 \text{ BTU/hr} \]

\[ E103 \text{ HS} - 6.25" \text{ Long} - 3 \text{ diode per HS} \]

\[ \begin{align*}
\text{IVS} \\
160 &\quad 180 \\
165 &\quad 111.5 \\
170 &\quad 121.91 \quad \text{IVS} = 170.5^\circ F \\
171 &\quad 124 \\
170.5 &\quad 123.4
\end{align*} \]
\[ T_f = 70.5 + 12(1.95)(12) = 212.6^\circ F \]

**V**

10 HP - 240 Volt

Trans/leg = 25.9 amper

Assume one SC265 diode per

Leg - PDL = 26.0 watts per leg

Assume one E103 - 6.35" HS pen

diode - \( R_dL = 1.10 \, \text{ohms} \)

\[ T_{hi} = 115 - 26(110 + 4) = 76^\circ C \]

\[ E_{PD} = 26(3.4) = 88.6 \, \text{mg} / \text{hr} \]

\[
\begin{array}{c|c}
\text{THI} & \text{EQ} = \text{PP.60} \\
150 & 91.27 \\
155 & 91.09 \\
156 & 87.10 \\
153 & PP.12 \\
152.5 & PP.12 \\
152.6 & PP.3 \\
154 & PP.10 \\
\end{array}
\]

\[ T_2 = 154 + 26(1.5 \, \text{Ah}) = 224.2^\circ F \]

\[ \frac{12.22}{17.18} \]

Three SC265 - 3 \times 4.24 = \frac{6.71}{12} \times 3.65 = \frac{6.16}{\text{(86.06)}}
If two diodes per line are used:

\[ I_{\text{max}} / \text{diode} = 25.9 \text{ amps} \]

\[ I_{\text{max}} / \text{diode} = 13 \text{ amps} \]

\[ P_d / \text{diode} = 10 \text{ watts} \]

\[ T_f = 115 - 10 (210 + 4) = 100^\circ F \]

Assume two heat sinks are used.

Three diodes per line.

\[ P_d / \text{HS} = 30 \text{ watts} - E103-6.25 \]

\[ \Sigma P_d / \text{HS} = 30 (3.41) = 102.3 \]

\[
\begin{array}{ccc}
T_{\text{HS}} & \Sigma P_d & E103-6.25 \\
190 & 166.25 & \\
150 & 81.25 & \\
160 & 101.15 & \\
162 & 105.23 & \\
161 & 103.2 & \\
160.5 & (102.15) & \\
\end{array}
\]

\[ T_f = 160.5 + 10 (25)(0.8) = 172.5^\circ F (86.4^\circ C) \]

(Need the 6.25" length to mount all the components)

Cos T:

\[
\begin{align*}
& \frac{6 - 1.265}{6 (4.24)} = 25.44 \\
& 17 \times 5/2 \times 0.788 \times 4 = 7.78 + 1.10 = 8.88 \\
& H_s - (2.65) (6.25) \frac{2}{12} = 4.11 \\
\end{align*}
\]

38.13
Assume 3760 section -

One heat sink for all chokes - two
diode per line -

From before - TH = 2170°F

\[ P_d / i_s = 5 / 10 = 60 \text{ watts} \]

Assume \( L = 6.75'' \)

\[ P_d = 60 \times (2.41) = 204.6 \]

<table>
<thead>
<tr>
<th>THI</th>
<th>20</th>
<th>= 204.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>196.5</td>
<td></td>
</tr>
<tr>
<td>175</td>
<td>213.8</td>
<td></td>
</tr>
<tr>
<td>173</td>
<td>206.9</td>
<td></td>
</tr>
<tr>
<td>172</td>
<td>203.2</td>
<td></td>
</tr>
<tr>
<td>172.5</td>
<td>205.1</td>
<td></td>
</tr>
<tr>
<td>172.7</td>
<td>204.4</td>
<td></td>
</tr>
</tbody>
</table>

\[ T_{Hi} = 172.3°F \]

\[ T_2 = 170.0 + 10 (1.5) (45) = 199.3 \text{ (92.9°F) } \]

Margin = 22.1°F

Cont -

\[ G - 5 (265 \text{ diode} - 6 (4.24) = 25.44 \]

\[ P_{int} = 25.44 \times 1.57 = 2.54 \]

Heat sink - \( (6.30)(6.25) / 12 = 3.54 \)

\[ \sqrt{3.54} = 1.8756 \]

\[ 20 \text{ HP - 440 volts} \]

Identical to the above
VII 20 HP - 240 Volt

**Amps/leg = 51.9 amps**

a) Assume 2 5-c 125 diodes per line - \( \text{Amps/diode} = \frac{51.9}{2} = 26 \text{ amps} \)

\( \text{Pd/diode} = 26 \text{ watts} \)

Assume 6 diodes on the heat sink

**E 360 section - 6.75" long**

\( \text{EPd} = 6 \times (26) (3.41) = 531.96 \)

\( \text{THS max} = 115 - 1.5(26) = 76.8^\circ C \)

\( \text{EQ} = \frac{531.96}{130.71} = 4.05 \)

\( \text{THS > 200^\circ F} \)

- The heat sink temperature is excessive

b) Assume 2 diodes per line

3 heat sinks - each **E 360 section**

**2" long**

\( \text{EPd} = 26 (2) (3.41) = 172.32 \)

\( \text{EQ} = 172.32 \)

\( \text{150^\circ} \)

\( 46.79 \)

\( 150^\circ \)

\( 10.11 \)

\( 200^\circ \)

\( 10.9 \)

\( \text{THS > 200^\circ F} \)

and is not

\( \text{OK} \)
3) Assume 3" long section - 2 D/line
S.P.D. = 177.32

\[ \theta_5 = 177.32 \]

\[
\begin{align*}
150 & \quad 65.7 \\
170 & \quad 91.97
\end{align*}
\]

4) Assume 6.75" long section - 2 D/line

\[ \theta_5 = 177.32 \]

\[
\begin{align*}
150 & \quad 100.22 \\
160 & \quad 162.17 \\
165 & \quad 179.67 \\
165 & \quad 176.10
\end{align*}
\]

\[
T_2 = 165 + 26(1.5)(0.1) = 235.2 (118^\circ)
\]

2" code margin -

\[
\begin{align*}
\cos \theta & = -0.6 \\
\sin \theta & = 0.265, \text{ divide } - 4.24 \times 6 = 25.44 \\
H_5 & = 6.75 (6.75) (3) = 10.63 \\
\text{Box } & = 15" \times 15" \times 4" = 17.46 + 261 = 28.14 \\
& = 56.21
\end{align*}
\]

c) Assume 12 x 5 x 4 box

Oil cooler on one H.S. - E 860 - 12" Long
\[ E_{pd} = 26.6 \times (3.94) = 53.196 \]  

**1) Assume: 12x15x4" Box**  

**E360-15" Long E360 Section**  

\[ E_{pd} = 53.196 \]  

<table>
<thead>
<tr>
<th>( T )</th>
<th>( E_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>214.14</td>
</tr>
<tr>
<td>140</td>
<td>204.4</td>
</tr>
<tr>
<td>130</td>
<td>194.7</td>
</tr>
<tr>
<td>120</td>
<td>185</td>
</tr>
<tr>
<td>110</td>
<td>175.3</td>
</tr>
</tbody>
</table>

\( T > 210^\circ F \) and is not acceptable.

**2) Assume: 12x18x4" Box**  

**E360-12" Long - 24/line**  

\[ E_{pd} = 53.196 \]  

<table>
<thead>
<tr>
<th>( T )</th>
<th>( E_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>304.16</td>
</tr>
<tr>
<td>160</td>
<td>327.8</td>
</tr>
<tr>
<td>180</td>
<td>353.7</td>
</tr>
<tr>
<td>175</td>
<td>456</td>
</tr>
<tr>
<td>170</td>
<td>539</td>
</tr>
</tbody>
</table>

\( T > 180^\circ F \) and is still unacceptable.

**h) Assume: 18"x24x6" Box**  

**E360-24 - 24/line**
\[ \text{EPd} = 521.96 \]

<table>
<thead>
<tr>
<th>Source</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_5 )</td>
<td>( 390.76 )</td>
<td>( 416.17 )</td>
</tr>
<tr>
<td>( 160 )</td>
<td>( 335 )</td>
<td>( 160^\circ F )</td>
</tr>
<tr>
<td>( 165 )</td>
<td>( 525 )</td>
<td>( \quad )</td>
</tr>
</tbody>
</table>

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### Cost
- 6 sc 265 choc \( = 4.25 \times 6 = 25.44 \)
- \( H_5 = \left( \frac{2.4}{12} \right) (1) = 12.60 \)
- \( 13.5x \times 6 \text{ cen} \)
- \( 40.54 + 4.60 = \frac{47.54}{4} = 11.88 \)

### Assumptions
1. Assume 2 choc per line:
   - Inmm/choc = \( 51.9 = \frac{17.3 \text{ amp}}{3} \)
   - Pd/choc = \( 15 \text{ watt} \)

\( \text{Htg. max} = 115 \times 0.01 = 115 \times 15 \text{ cent} = 420.5^\circ F \)

Assume all chocder on one heat sink \( 5360 \text{ - 8" long} \):

\( \text{Pd}/\text{H}\& = 15 \times (9)(3.41) = 460.35 \)

\[ \text{EPd} = 460.35 \]

<table>
<thead>
<tr>
<th>Source</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 150 )</td>
<td>( 154.14 )</td>
<td>( \quad )</td>
</tr>
<tr>
<td>( 180 )</td>
<td>( 267.54 )</td>
<td>( \quad )</td>
</tr>
<tr>
<td>( 200 )</td>
<td>( 350 )</td>
<td>( \quad )</td>
</tr>
</tbody>
</table>

\( \text{and it is unaccated} \)
2) Assume 3 chokes per line

Assume choke = 12.3 amps per choke

10" long E360 section

\[ T_{th} \quad E_{rd} = 460.05 \]

- 190: 327
- 200: 374
- 210: 427
- 220: 481
- 230: 534
- 240: 591
- 250: 663

and is unacceptable

3) Assume 3 chokes per line

Assume choke = 15 watts

12" long E360 section

\[ T_{th} \quad E_{rd} = 460.25 \]

| 160 | 307 |
| 175 | 405 |
| 180 | 490 |
| 190 | 494 |
| 195 | 495 |

\[ T_2 = 195 + 15(0.5) \times 18 = 235.5^\circ F (113^\circ C) \]

(1°C margin)
\[ \text{Cost} = 9 \times 5.265 \text{ dollars} = 32,135 \text{ dollars} \]

\[ \text{Hrs} = 6.30 \times \frac{18}{12} = 9.45 \text{ hours} \]

\[ \text{Box} = 10 \times 12 \times 4 = 114.14 + 172 = \frac{127.26}{12} \text{ feet} \]

4) **Try**ing 3 \underline{\text{axles}} \underline{\text{line}} - Each

\text{line} \underline{\text{with its own heat sink}}

\[ T_{\text{max}} = 154.5^\circ F \]

\[ P_d / H_r = 15 \times (3) \times (0.41) = 15.345^\circ F \]

\underline{\text{E360° section}} - 4" long

\[ T_{\text{HS}} \leq 153.45^\circ F \]

150
160
170
180
190
182

\[ T_d = 182 + 15 \times (75) (18) = 2228^\circ F (1055^\circ C) \]

\[ 115 - 105.5 = 4.2^\circ C \]

\[ \text{Cost} = 9 \times 4.24 \text{ dollars} = 38,16 \]

\[ \text{Hrs} = 6.30 \times \frac{4}{12} = 2.10 \text{ hours} \]

\[ \text{Box} = 10 \times 15 \times 4 = 14.14 + 232 = \frac{17.18}{9} \text{ feet} \]
Assume 4 diodes per line

\[ I_{\text{rms/diode}} = \frac{51.9}{\sqrt{7}} \quad \text{amps} \]

\[ P_{d/diode} = 10 \quad \text{watts} \]

Assume one heat sink - \( L = 10'' \)

\[ P_{d/m} = 12(10)(3.44) = 409.2 \]

\[ T_{\text{thrmx}} = 115 - 10(10) = 10500 = 2120^\circ F \]

\[ T_{\text{HS}} = 52 = 409.2 \]

<table>
<thead>
<tr>
<th>( T )</th>
<th>( \text{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>323.86</td>
</tr>
<tr>
<td>190</td>
<td>374.68</td>
</tr>
<tr>
<td>200</td>
<td>427</td>
</tr>
<tr>
<td>196.7</td>
<td>409.25</td>
</tr>
</tbody>
</table>

\[ T_2 = 196.7 + 10(1.5) = 222.2(06.2^\circ F) \]

\[ M_{\text{avg}} = 115 - 106.2 = 8.8^\circ F \]

\[ C_{\text{HS}} = 12 \times 4.24 = \text{diode conv} = 50.88 \]

Heat sink = \[ 6.80 \left( \frac{10}{12} \right) = 5.25 \]

\[ D_{\text{HS}} = 8 \times 10 \times 4'' = 8.57 + 1.20 = 9.77 \]

\[ \frac{165.23}{9.77} \]
N) Considering Section EX98

Cost per foot - estimated as

\[ \frac{3.65}{1.57} = 2.406 \text{ /ft.} \text{ in}^2 \text{ (E103)} \]

\[ \frac{6.38}{2.2} = 2.96 \text{ /ft.} \text{ in}^2 \text{ (E369)} \]

\[ \frac{4.689}{2.96} = 1.6 \text{ /in. foil} \]

\[ P_n = 1.0 = 9.725 + 1.32(2) = 12.52 \]

\[ P_n = n = 1.0 \text{ (46)} = 46 \]

\[ Ax/16 = 65.7 - 9.725 = 56.25 \]

\[ w = 10 \quad d = .25 \quad l = 6.25 \]

\[ R_2 = \frac{w}{10} = \frac{1.0}{46} \quad R_1 = \frac{l}{d} = \frac{6.25}{.25} \]

\[ F_2 = .78 \quad F_A = 1.0 - .78 = .22 \]

If \[ L = 2" \quad R_1 = \frac{l}{d} = \frac{2}{.25} = 8 \]

\[ F_1 = -2 = F_A = 1.7 = -3 \]

\[ F_A = .3 \quad F_A = .3 \]

Assume Two anchors per line per wk

\[ SC \text{, } TH \text{ max } = 168.1°F \]

\[ P = \frac{1}{14} = 84 (3.41) = 184.14 \]

\[ l = 2.0" \]
Assume \( L = 4" \) \( F_u = 0.26 \)

\[
\begin{align*}
\text{THV} & \quad S_0 = 122.72 \\
150 & \quad 63.42 \\
150 & \quad 120 \quad \therefore \text{THV} > 165 \\
& \quad \text{and is unaccount}
\end{align*}
\]

\[
\begin{align*}
\text{THV} & \quad S_0 = 122.72 \\
170 & \quad 181.94 \\
160 & \quad 175.6 \quad \therefore \text{THV} = 165.5 \\
160 & \quad 177.12 \quad \text{and is marginally acceptable} \\
\end{align*}
\]

Cost \( 6 \times \$0.265 = 6 \times 4.24 = 25.44 \)

\[
\begin{align*}
\text{HR} & \quad 12.72 \left( \frac{4}{12} \right) (3) = 12.72 \\
\text{Box} & \quad 12" \times 15" \times 4 = 144 + 2.72 = 17.18 \\
\end{align*}
\]

\[
\begin{align*}
\text{Total} & \quad \$57.34
\end{align*}
\]

\[
\begin{align*}
\text{VIII} & \quad 30 \text{ HP} - 4.80 \text{ volts}
\end{align*}
\]

\[
\begin{align*}
\text{Current/leg} & \quad 72.8/2 = 36.9 \text{ amps} \\
\text{If one choke per leg is used} & \quad \text{SC 265} \quad P_d = 44 \text{ watts} \\
\text{THM} & \quad 115 - 44 (15) = 49 \quad \text{100%}
\end{align*}
\]

\[
\begin{align*}
\text{Which is very low}
\end{align*}
\]
a) Consider 2 chiller parts

\[ \text{Trans/chuckle} = 19.5 \text{ cm}^2 \]
\[ \text{Pd/chuckle} = 18 \text{ watts} \]

\[ T_{\text{in}} = T_{\text{j}} - q_{2R} = 115 - 18(15) = 84.0 \text{ °C} \]

Assume E36° section 12" long
(12 heat sink) - 6 chiller

\[ Pd/145 = 18^2 (6)(3.75) = 368.2 \text{ W} \]

\[ \dot{Q} = 368.2 \text{ W} \]

\[ 180 \]
\[ 178 \]
\[ 177 \]
\[ 176 \]
\[ 175 \]

\[ T_2 = 178 + 18(15)(1.5) = 226.6 \text{ °F} \]

\[ \text{Margin} = 7 \text{ °C} \]

\[ \text{Cont.} = 6.5 (265.4 + 0.6(5.15)) = 30.84 \text{ W} \]

\[ H_4 = \frac{12}{10} (6.00) = 6.00 \text{ W} \]

\[ P_{\text{total}} = 8'' \times 10'' \times 4'' = 9.22 + 1.38 = \frac{10.60}{48.24} \]

b) Assume 2 chiller per line

and one H.S. 12" long.
The heat sink is marginal. Less scrap page with 10" length.

2) Assume three heat sinks -

Two socks per Hrs - 

\[
Pd/\text{Hrs} = 3.6 (3.41) = 12.376\]

\[
\text{T HS} = E P d = 12.376
\]

\[
170 \quad 126.1^\circ F
\]
\[
169 \quad 123.4^\circ F
\]
\[
168.5 \quad 120.8^\circ F
\]

\[
T_d = 168.5^\circ F + 18\times (1.5^\circ F) = 217.2^\circ F (1.021)
\]

Margin = 12.0

3) HP - 240 V 1015 -

\[
\text{Input per leg} = 77.8\text{ amps} -
\]

Assume 4 diode per leg

\[
\text{Input/diode} = 77.8 = 19.45\text{ amps}
\]

\[
Pd/diode = 18\text{ kWatts}.
\]
The max = 190.4°F

Assume Two Heat sinks - ea. 12” long
E360 section (12 diode Total)

10-6 diodes per hr -
Pd/hr = 6 (14) (0.49) = 368.28

THS

EQ = 368.28

178.6

$\theta_{j} = 178.6°F$

$T_{2} = 178.5 + 18 (1-5) (69) = 207°F (104.5)$

I 40 HP - 480 V0115 -

\[\text{Irms/leg} = \frac{\text{HP. (746)}}{173 \text{ Vrms (eff.)} (48)}\]

\[= \frac{40 (746)}{173 (480)(1.73)} = 51.9 \text{ amps}\]

(same as 20 HP - 240 V0115)

II 40 HP - 240 V0115

\[\text{Irms/leg} = 51.9 (2) = 103.8 \text{amps}\]

6) Assume 6 diodes/line

\[\text{Irms/diode} = \frac{103.8}{6} = 17.3 \text{amps}\]
Pd/Choke = 15 watts ea

Thermal issue: $T_f - QER = 115 - 15(2.5) = 92.5^\circ C$

$6 \times 3 = 18$ Chokes Req'd

Assume 9 Chokes per hr -

$Pd/hr = 9(15)(3.41) = 460.37$

Assume $L = 15''$ long

\[
\begin{align*}
\text{THS} & \quad \quad 30 = 460.37 \\
140 & \quad \quad 45.9.03 \\
140.2 & \quad \quad 461.15
\end{align*}
\]

$\therefore$ THS = 140.2°F

$T_2 = 180.2 + 15(1.5)(0.8) = 200.7^\circ F$

Cost -

Choke - $18 SC265 = 18(4.24) = \$76.72$

$Hs - 6.30 \left( \frac{15}{12} \right) (2) = \$15.75$

Box $15 \times 15 \times 4$ sheven - $17.46 + 2.68 = \$20.14$

\[ \frac{11.2}{1} \]
Checking the previous calculations

1) 5 HP 440V 3Ph

Irms/leg = 7.2 amps

Using one sc250 chokc per leg

Irms/chokc = 7.2 amps

Pd/chokc = 1 W per

Rg-c = 1.75°C/Watt

Ths max = 115°C + (0.35°F)

= 92.8°C (208.0°F)

Using one E103 heat sink for all

Order - Pd/heat sink = P(3.24)

L = 6.75""

THS

148

148

150

5.31

29.44

81.37

THS = 150°F

\[ T_F = 150 + 8 \times (1.75 + 4) \times 1.8 = 180.96°F \]

Margin = 115 - 82.7 = 32.3°F
II 5 HP 240 Volts

\[ \text{Innt/leg} = 14.8 \text{ amperes} \]

Using one SC260 diode per leg,

\[ \text{Innt/diode} = 14.8 \quad \text{Pd/diode} = 144 \text{ Watts/lg} \]

\[ R_{2-0} = 1.55 \text{ ohms} \]

\[ T_{\text{max}} = T_{j} - Q \cdot R = 115 - 14 \cdot (1.55 + 4) \]

\[ = 87.9^\circ \text{C} (190.46^\circ \text{F}) \]

Using one E103 HS - 6.75” Long for all the diodes:

\[ \text{Pd/hs} = 14 (3.75) = 143.72 \text{ Watts/hs} \]

\[ \text{Innt} \quad \text{Ed} = 143.72 \]

179 141.51
150 143.71

\[ \therefore \text{The} = 140^\circ \text{C} \]

\[ T_{j} = 180 + 14 (1.95) (0.8) = 229.14^\circ \text{C} (442.64^\circ \text{F}) \]

\[ \text{Margin} = 115 - 109.5 = 5.5^\circ \text{C} \]

III 10 HP 480 Volts

Same as the above – except

\[ \text{Innt} = 25.5/2 = 13 \text{ amperes per leg} \]

\[ \text{Pd} = 12 \text{ watts/diode (SC260)} \]

\[ \text{Pd/hs} = 12 (3) (3.75) = 122.76 \quad \text{THN} = 170.5^\circ \text{C} \]

\[ T_{j} = 170.5 + 14 (1.95) (1.8) = 312.62^\circ \text{C} (578^\circ \text{F}) \]
**IV. 10 HP - 240 Volts**

\[ I_{\text{rms}}/\text{leg} = 25.9 \text{ amps} \]

Using 2-SC265 diodes per line

\[ I_{\text{rms}}/\text{diode} = 13 \text{ amps} \]

\[ P_d/\text{diode} = 10 \text{ watts} \]

\[ R_{y-e} = 1.15 \text{ °C/watt} \]

\[ T_{\text{th mox}} = T_f - A_2 R = 115 - 10(C_{11}+4) \]

\[ = 100 \text{ °C} \quad (210 \text{ °F}) \]

Using one E360-6.75 section for all

The diodes (3)

\[ P_d/\text{heat sink} = 6(C_{10})(3.41) = 204.6 \text{ kW/ hr.} \]

\[ T_{HS} \]

\[ 172.2 \]

\[ 172.3 \]

\[ T_{HS} = 172.3 \text{ °F} \]

\[ T_2 = 172.3 + 10(C_{1.5})(1.5) = 193.3 \text{ °F} \quad (95.8 \text{ °C}) \]

\[ P_{\text{heat}} = 115 - 92.9 = 22.65 \text{ °C} \]
Considering the use of a 6" heat sink - (was 6.75")

I - 1 HP 240V @ 480 VOLT - no heat sink required

II a) 5 HP - 480 VOLT - open -

b) 1 HP - 240 VOLT - Irms/leg = 14.8a

Pd/diode/leg = 14 watts

Pd per heat sink @ 3 diodes per heat sink = 42 watts.

Considering an E123 section -

\[ \Sigma Pd = 42 \times 3.12 = 143.22 \]

\( E \) = 6.75 \( T_h = 180^\circ F \) \( \rho_d = 143.22 \)

\( E \) = 6.00

<table>
<thead>
<tr>
<th>THS</th>
<th>Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>139.82</td>
</tr>
<tr>
<td>186</td>
<td>141.86</td>
</tr>
<tr>
<td>187</td>
<td>143.90</td>
</tr>
</tbody>
</table>

\[ T_2 = THS + \Sigma Pd = 187^\circ F + 14(1.55 + 1.4) \text{ ft} \]

\[ = 236.19^\circ F (113.4^\circ C) \text{ which is acceptable} \]
III. 30 HP - 240 Volts

*Current = 77.8 watts per leg*

c) Require \( 240 \sqrt{2} = 339 \text{ min} \)

*Voltage variation -

Consider one \( 8420 \text{ D (50A)} \)

\( R_y = 0.4 \text{°C/watt} \)

\( T_2 \text{ max} = 110^\circ \text{C} \)

\( R_c = 0.2 \text{°C/A} \) (sec. 4.1)

IE package \( 1/2-20 \text{ stud} -1.05 \text{ HEX} \)

Contact area = 0.66 in^2

c) \( I = 30 \text{ BTu/in} \)

\( A = 0.020 \text{ in. thick} \)

\( A = 0.66 \text{ in}^2 \)

\( \rho = \frac{T}{N^2} = \frac{0.020 (144) (3.41)}{30 (66) (1.8)} = 0.28 \text{ ohm} \)

\( R = EI = 72 \text{ in.} (150) = 116.7 \text{ watts} \)

\( T_{hr} \text{ (max)} = T_2 - 80 \text{°R} \)

\( = 110^\circ \text{C} - 116.7 (4 + 2^\circ) = 30.6^\circ \text{C} \)

*Considering an E123 heat sink*

\( t = 6.0^\circ \text{C} \)
b) Consider Two T64200 diodes in parallel.

\[
I_{\text{r.m.s.}}/\text{diode} = 77.9/2 = 38.9 \text{ amps}
\]

\[
\text{Power/diode} = EI = (15)(0.85) = 58.35 \text{ watts}
\]

Package Type - 5-1 - 1/4-2P stud with .554" hex

\[
R_{\text{2-c}} = 1.0 \ \degree\text{C}/\text{watt}
\]

\[
T_{\text{2 max}} = 110\degree \text{C}
\]

\[
\Theta_{\text{oa}} = \frac{30 \text{Rhm} \cdot \frac{1}{2}}{\text{Inf} + 2} = 1.01 \degree \text{C/m}
\]

\[
R_{\text{chm}} = \frac{1}{R_{\text{2-c}}} = \frac{.900}{(45)(.25)} = 1.01 \degree \text{C/m}
\]

\[
T_{\text{hmax}} = T_{\text{2 max}} - Q\Theta_{\text{ek}} = 110 - 58.35 (1.0 + 1.0) = -7.2^\circ\text{C max}
\]

c) Consider Two T64200 diodes per leg - \(P_d/\text{diode} = 58.35\ \text{watts}\)

\[
R_{\text{2-c}} = .4^\circ\text{C}/\text{watt} - R_{\text{chm}} = .23^\circ\text{C/m}
\]

\[
T_{\text{h max}} = 110^\circ\text{C} - 58.35 (.4 + 25) = 70.32^\circ\text{C}
\]

\(159^\circ\text{C max}\)
Considering an E360 H.S.
Two drocer per H.S. - \( Pd/Hs = 5.35 \times 2 \)
\( L = 6.0" \)

\[ T_{HI} = \text{PD} = 392.95 \]

| 200 | 276 |
| 250 | 463 |
| 275 | 440 |
| 300 | 367 |
| 325 | 380 |
| 375 | 393 |
| 400 | 400 |

\[ T_D = 233.5 + 54205 \times (0.6) = 304.9^\circ F (101^\circ C) \]

Considering an E612 H.S.
One drocer per H.S.
\( Pd/Hs = 58.25 \text{ watts} \)

For 5" long H.S. - \( R_{hs} = 11^\circ F/\text{ft} \)
\[ AT = QE = 54.21 \times (0.1) = 64.62^\circ \]

\[ Thr = 100^\circ F + 64.62^\circ F = 216.62^\circ \]
30 HP - 480 volts

Considering - 3 legs = 38.9
Pd/leg = EI = 1.5(38.9) = 58.35 watt

Consider Two diodes per leg
Tetron (2D) isolated case -
Pd-c = 10 °C/Hatt
Pd-tet = 10 °C/Hatt
Pd/diode = 58.35/2 = 29.18 watt

Thermoc - T - 2QR = 110 °C - 29.18(10+20)
= 51.35 °C (124.7 °F)

Considering on 360 Ht
Pd/ht = 29.18(3) = 87.56 watt
L = 60” Pd = 199.008

Thet
5Pd
12’’
200
175
177

= T = 177°F + 25.18(200)(1.8) = 280.9°F (325.9 °C)

If L = 60”
\[ T = 163 + 29.1 \varphi (20^2) \text{C.P} = 269^\circ F (131.7^\circ C) \]

Consider an E 2PP HS.

\[ L = 4.00'' \]

\[ T = 163 + 29.1 \varphi (20^2) \text{C.P} = 269^\circ F (131.7^\circ C) \]

\[ T = 140 + 29.1 \varphi (20^2) \text{C.P} = 254^\circ F (123^\circ C) \]
Considering 10 HP - 480 volt.

\[ T = 6400 \text{ N} \quad P_{cc} = 1.0 \quad R_c + R_n = 1.01 \]

\[ \text{Imp/
/leg} = 22.9/2 = 13 \text{ amper} \]

\[ \text{Pot / leg} = 2T = 13 \text{ C}_o \approx 19.5 \text{ watt} \]

\[ T_{\text{max}} = T_2 - 2\sqrt{R} = 110 - 19.5(2.0) \]

\[ = 70.81^\circ C (159.45^\circ F) \]

Considering an E 103 HP.

\[ L = 6.0 \text{ inch} \quad 3\text{ amper} \text{ checks per leg} \]

\[ \begin{array}{c}
140 \\
145 \\
147 \\
146
\end{array} \]

\[ \begin{array}{c}
56.36 \\
64.79 \\
68.22 \\
66.5
\end{array} \]

\[ \sqrt{T_2} = 146^\circ F + 19.5(2.0)(1.8) = 216.51^\circ F \]

\[ (102^\circ C) \]

\[ \text{The configuration is acceptable.} \]

\[ Q = \text{Km A to Tank mL} \]

\[ \frac{T_x - T_f}{T_x = 2 - 14} = \frac{T_x = 0 - 14}{200 mL} \]

\[ Q = h_T A \Delta T \]

\[ h_T = \frac{Q}{A \Delta T} \]

\[ = \frac{19.5 (3.4)}{(20.0) .63}(3) \]

\[ h_T = 172.9 \text{ BTU} \]
\[ M = \sqrt{\frac{h \cdot c}{\delta^4}} = \sqrt{\frac{1.729(30.063)(1.74)}{12(110)(1.57)}} \]

\[ M = 1.579 \]

\[ T_x = T_f + \frac{T_{x=0} - T_f}{\text{water ml}} \]

\[ T_x = 100^\circ F + \frac{146 - 100}{\cos(\frac{1.579 \times 3}{12})} = 142.65^\circ F \]

- The drop down the fin is only 35^\circ F
Considering $2040$ - $480$ volt

\[ T = 6420 \text{ N} \quad B-c = 10 \quad \text{Rc-wf} = 101 \]
\[ \text{I/leg} = \frac{510}{2} = 25.5 \text{ amper} \]
\[ \text{Pd/leg} = 25.5 \times (1.0) = 25.5 \text{ watt} \quad \text{per leg} \]
\[ T_{\text{max}} = T_j - \text{EVR} = 110 - \frac{38.93}{2} (1.0 + 1.0) \]
\[ T_{\text{max}} = 70.87^\circ \text{C} \quad (154.5^\circ \text{F}) \]

Assume 2 diodes per heat sink - E193 Type L = 6"

\[ \text{EPD} = 38.93 \times (3.41) = 132.75 \]
\[ 140 \quad 56.36 \]
\[ 175 \quad 119.16 \]
\[ 190 \quad 150 \quad - \text{ Ths} = 185^\circ \text{F} \quad \text{which is excessive} \]
\[ 139 \]

Assume 2 diodes per heat sink

\[ \sqrt{E} \quad \text{Type L = 6"} \quad \text{100x50c 13x15x4"} \]

\[ \text{EPD} = 132.75 \text{ BTU/hr} \]
\[ 140^\circ \text{F} \quad 90.54 \]
\[ 145 \quad 104.19 \]
\[ 150 \quad 118.2 \quad - \text{ Ths} = 185^\circ \text{F} \]
\[ 160 \quad 147.33 \]
\[ 155 \quad 172.6 \]

\[ T_j = 155 + \frac{38.93 \times 2.01}{7.8} = 225.42^\circ \text{F} \quad (107^\circ \text{C}) \]
Considering the 30HP - 240 Volt Condition Again

a) 2 idler per line

Item/line = 27.8 amperes

Item/choke = $\frac{27.8}{2} = 13.9$ amperes

Considering an SC 265 - 42 watt/choke

$R_{c-c} = 110$ ohms  $R_{c-hs} = -4.9$ ohms

$T_{m\text{ax}} = 115 \degree C$

$\theta_{m\text{ax}} = T_{m\text{ax}} - QER = 115 - 42 (11 + 4) = 52 \degree C$

Using 2 SC 265 (Low HS Temp Regime)

$Pd/hrs = 42 \times 2 = 84$ Watts  $\frac{P_d}{kW} = 2.66$ W/kW

Assume $E_{2HP HS} = 6.0''$

<table>
<thead>
<tr>
<th>THS</th>
<th>EPD 286.41</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>24.7</td>
</tr>
<tr>
<td>150</td>
<td>165</td>
</tr>
<tr>
<td>175</td>
<td>270</td>
</tr>
<tr>
<td>180</td>
<td>293</td>
</tr>
</tbody>
</table>

$T_{m\text{ax}} = 179 \degree F$

Which is excessive.

If indium foil is used

$R_{c-hs} = 0.1$ ohms

$\theta_{m\text{ax}} = T_{m\text{ax}} - QER = 115 - 42 (11 + 4) = 64.6 \degree C$

(140\degree F)
Which is still too low -

If each diode has a $E=2.66$

Type heat sink - $L=6''$

$P_d = 42(3.4) = 143.22$ W

$\text{EPD} = 143.22$

<table>
<thead>
<tr>
<th>$I_{d1}$</th>
<th>$I_{d2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>25.17</td>
</tr>
<tr>
<td>150</td>
<td>73.44</td>
</tr>
<tr>
<td>160</td>
<td>91.44</td>
</tr>
<tr>
<td>180</td>
<td>129</td>
</tr>
<tr>
<td>185</td>
<td>139</td>
</tr>
<tr>
<td>187</td>
<td>143</td>
</tr>
</tbody>
</table>

Which is excessive even with indium foil

$\therefore 2$ diodes per half max of the $5C265$ Type are out -

Consider $TP4000$ (EE - isolated case)

$R_{eq} = 4.0^\circ F/\text{Aatt}$ $R_{c11} = .2^\circ F/\text{Amm}$

Assume two diodes per line -

$I_{lim}/\text{leg} = 72.0$ amp

$I_{lim}/\text{diode} = \frac{72.0}{2} = 36.0$ amp

$P_d/\text{diode} = EI = 15(36.0) = 540 W$

$T_{ij\max} = 110 - 540 (1.4 + 2f) = 70.32^\circ C$

$\left(158.6^\circ F\right)$

$P_d/\text{hr} @ \text{one diode per hr} = 54.35(3.4) = 188.9$
If \( L = 9'' \) E103 section is assumed

\[
\begin{array}{c|c}
\text{Test} & \text{EPd} = 15850 \\
140 & 10.34 \\
160 & 130.14 \\
165 & 143 \\
185 & 140
\end{array}
\]

\[ T\text{hr} = 185^\circ F \]

From IEC chart

\[ R L = 9'' = 0.6 (P_{Lx} = 2) = 0.6 (1.5) = 1.0 \text{ ft}^2 \text{ h} \]

\[ T\text{hr} = 100 + (58.35 \times 20.8) \text{ h} = 213^\circ F \]

which is excessive —

E613 Type HS: 6'' Long

\[ R L = 6'' = 0.7 (\text{ch} 1) = 0.77^\circ \text{C} \text{ h} \]

\[ T\text{hr} = 100 + 58.35 \times 0.77 \text{ h} = 180^\circ F \]

E613 Type HS: 9'' Long

\[ R L = 9'' = 0.6 (\text{ch} 1) = 0.66^\circ \text{C} \text{ h} \]

\[ T\text{hr} = 100 + 58.35 \times 0.66 \text{ h} = 169.5^\circ F \]

E613 Type HS: 13'' Long one diode/hr.

\[ R L = 12 = 0.57 (\text{ch} 1) = 0.57^3 \]

\[ T\text{hr} = 100 + 58.35 \times 0.57^3 \text{ h} = 161.2^\circ F \]

\( \sqrt{\text{we would need a E613 HS - 9'' Long one TPS2000 diode per HS - Two diode}} \)
If one used E615 Type H5

\[ R_{L} = 12'' = 0.81^\circ C/W \]

Consider two diodes per heat sink

Total power per H5 = 57.35 x 2 = 114.7 watts

a) From IERC -

\[ R_{L} = 3'' = 0.81^\circ C/W \]

\[ R_{L} = 12'' = 0.53 (0.4)^2 / W = 0.43^\circ C/W \]

Using the D-7 reduction factor -

\[ R_{L} = 12'' = 0.43 x 7 = 3.01^\circ C/W \]

\[ THS = 100^\circ F + 114.7 (2^\circ C)(1.8) = 163.2^\circ F \]
b) Using Ahom Data -

10" Long - Two devices per 1 hr.

Area per device = 71.4 (6) = 428.4 in²

$R_{ohm} = \frac{0.57 \, \text{ohm}}{7} = 0.081 \, \text{ohm/m}

$R_{ohm} = \frac{0.081}{2} = 0.041 \, \text{ohm/m}$

$Ths = 100^\circ F + 116.7(-2)(1.5) = 142^\circ F$

c) Using The Formula

\[\frac{Ths}{116.7} = 139\]

130
155
150
145
147
146

240
451.56
438
338.6
407
397

Which agrees with the above results.

Used: L = 12", I = 1005, P = 1562

$P = 65 \, \text{in}^2/\text{in}$, $F_m = -0.6$, $A_f$ = 744 in²

CEG-15 Section

\[Ths = 142 + 58.4(-4 + 3D(1.5)) = 218.5^\circ F (104^\circ G)\]

Considering The 30 HP - 440 volt condition

Tons/leg = 728/2 = 364 amperes

Assume Two T642A0A motor in parallel.
\[ \beta - c = 10^\circ\text{C} / \text{hr}, \quad \beta - h = 241^\circ\text{C} / \text{hr} \]

\[ \dfrac{Pd}{chord} = \dfrac{35.5 \times 1.5}{2} = 25.18 \text{ in. water} \]

\[ T_{h5} = 110^\circ\text{C} - 25.18 \times (10 + 10) = 57.35^\circ\text{C} \]

(124^\circ F)

If two checkers per ft run are used-
Assume \( L = 10'' \) E615 section:

\[ \dfrac{Pd}{h5} = 2(29.18) (2.41) = 199.00 \]

\[ T_{h5} \]

\[ \sum Pd = 199.00 \]

\[ 110 \]
\[ 115 \]
\[ 120 \]
\[ 125 \]
\[ 126 \]
\[ 126.5 \]

- \( = T_{h5} = 126^\circ F \)

and is very close to being acceptable
5 HP 410 Volt - Condition

\[ I_{\text{res}} / \text{leg} = \frac{144 \text{ pA}}{2} \]

\[ P_{\text{d}} / \text{leg} = 24 \times (1.5) = 11.1 \text{ watts} \]

Assuming T6430N diode, one pair

\[ R_g - R_z = 1.0^\circ \text{C/m} \quad R_{\text{em}} = 101^\circ \text{C/w} \]

\[ T_{\text{th, max}} = T_2 - C_z R_z = 110 - 11.1 (101 + 10) \]

\[ = 87.69^\circ \text{C} \ (185.4^\circ \text{F}) \]

Assume three diodes on one

ED103 Type HSJ L = 6"

\[ P_{\text{d}} = 11.1 (7) (3.41) = 113.55 \]

\[ T_{\text{HSJ}} = 3P_{\text{d}} = 113.55 \]

150  \hspace{1cm} 70.44
160  \hspace{1cm} 91.40
170  \hspace{1cm} 110.18 \hspace{1cm} \underline{T_{\text{HSJ}} = 170^\circ \text{F}}
175  \hspace{1cm} 119.06
172  \hspace{1cm} 114.0

\[ T_2 = 172^\circ \text{F} + 11.1 (2.4) \text{C/F} = \]

ORIGINAL PAGE IS OF POOR QUALITY
18 HP - 240 V - 6" Long E360 HS

\[ \text{SPd} = 60 \times 3.41 = 204.6 \, \text{rpm} \]

\[ \text{THs} \quad \text{SPd} = 204.6 \]

<table>
<thead>
<tr>
<th>THs</th>
<th>SPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>170°F</td>
<td>172.76</td>
</tr>
<tr>
<td>175°F</td>
<td>193.44</td>
</tr>
<tr>
<td>180°F</td>
<td>199</td>
</tr>
<tr>
<td>182°F</td>
<td>204.6</td>
</tr>
</tbody>
</table>

\[ T_2 = \text{THs} + QSK = 178.5 + 10(110 + 4)\, \text{C} \]
\[ = 205.5 \, ^\circ\text{C} (391.9 \, ^\circ\text{F}) \]

20 HP - 240 VOLT

E360 section - 6" Long

Two driers per hr.

\[ \text{SPd} = 54 \times 3.41 = 184.14 \, \text{rpm/} \text{hr} \]

\[ \text{THs} \quad \text{SPd} \]

<table>
<thead>
<tr>
<th>THs</th>
<th>SPd</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>118</td>
</tr>
<tr>
<td>160°F</td>
<td>147.34</td>
</tr>
<tr>
<td>165°F</td>
<td>162.39</td>
</tr>
<tr>
<td>170°F</td>
<td>172.76</td>
</tr>
<tr>
<td>172°F</td>
<td>199</td>
</tr>
<tr>
<td>175°F</td>
<td>193</td>
</tr>
<tr>
<td>178°F</td>
<td>184</td>
</tr>
</tbody>
</table>

\[ T_2 = \text{THs} + QSK = 172°F + 26(110 + 4)\, \text{C} \]
\[ = 242.2°F (116.7°C) \]

which is a bit high
Looking at the 10 HP-470 unit –

Assume $E_{360} \text{ hr.} = L = 10''$
3 knock per heat sink

$$\text{Thr. mot.} = T_5 - Q_{\text{EV}} = 115^\circ - 19.5 \text{ (29)}$$
$$= 159.5^\circ F$$

$$5\text{ pdl/hr} = 3 \times (19.5)(0.4) = 199.5$$

$$\text{Thr.} \quad 5\text{ pdl} = 199.5$$

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>140.29</td>
</tr>
<tr>
<td>150</td>
<td>150.04</td>
</tr>
<tr>
<td>152</td>
<td>151.85</td>
</tr>
<tr>
<td>153</td>
<td>196.3</td>
</tr>
<tr>
<td>153.4</td>
<td>198.</td>
</tr>
</tbody>
</table>

$T_5 = \text{Thr.} + Q_{\text{EV}} = 153.5 + 19.5 \text{ (29) (29)}$
$$= 224.0^\circ F \text{ (106.2)}$$

Looking at the 20 HP 470 unit –

If one assumes Three knock per heat sink of the E360 type
Pd/diode = 19.5 \text{ watts} \\

T_{HR} \text{ max} = 159.5^\circ F \ \text{(REF PG 62)} \\
\Sigma Pd = 19.5 \times 3 = 58.5 \text{ watts} \\

\therefore \text{ Could use the same configuration as the } 10 \text{ hp, } 480 \text{ V but would need } 2 \text{ heat sinks } 10'' \text{ long} \\

__________

Looking at the 20 hp 240 volt unit again \\

26 watts = Pd/diode \\

If consider 3 diodes per HR. \\
\Sigma Pd/HR = 3(6.8) = 78 \text{ w} = 265.98 \\

T_{HR} \text{ max} = T_{T} - Q_{240} \\
= 115^\circ C - 26(110+4) = 76^\circ C \ \text{(168°F)} \\

Assume an E360 section - 2 = 10'' \\

<table>
<thead>
<tr>
<th>HR</th>
<th>\Sigma Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>227.9</td>
</tr>
<tr>
<td>165</td>
<td>251.2</td>
</tr>
<tr>
<td>167</td>
<td>260.6</td>
</tr>
<tr>
<td>170</td>
<td>270.2</td>
</tr>
</tbody>
</table>

\therefore \text{ HR } = 160^\circ F
$T = Tm5 + Q eR = 168^\circ F + 26 (15) Cm$

$= 238.2^\circ F (114.5^\circ C)$
APPENDIX K

THERMAL ANALYSIS, 3Ø CONTROLLERS, 150°F
Thermal Analysis
for Ivecco Controllers

\[ I_{\text{rms}} = \frac{H.P. (746)}{(1.73)(V_{\text{rms}})(\text{efficiency})(P.F.)} \]

Power per diode = EI (93 duty cycle)

Assume that from 10-30 HP,

\[ \text{efficiency} = 0.8 \text{ & } 1-5 \text{ HP, eff.} = 0.7 \]

P.f. = 0.866 in all cases.

\[ E = 2 \text{ volts} \]

\[ I_{\text{rms}} = \frac{30(240)}{(1.73)(240)(0.8)(0.866)} = 72.4 \text{A} \]

Power per diode = \( 2 \sqrt{72.4} = 155.6 \text{ watts} \)

\[ \text{100% duty cycle, Total power dissipation on the heat} \]

\[ S_{\text{in}} = 466.8 \text{ watts} \]
<table>
<thead>
<tr>
<th>HP (240V)</th>
<th>(I_{\text{rms}} , \text{per leg (amps)})</th>
<th>PD Watt/leg</th>
<th>EPD (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>77.5</td>
<td>155.6</td>
<td>466.8</td>
</tr>
<tr>
<td>20</td>
<td>51.9</td>
<td>103.7</td>
<td>311.2</td>
</tr>
<tr>
<td>10</td>
<td>25.9</td>
<td>57.8</td>
<td>157.6</td>
</tr>
<tr>
<td>5</td>
<td>14.8</td>
<td>29.6</td>
<td>88.9</td>
</tr>
<tr>
<td>1</td>
<td>2.96</td>
<td>5.93</td>
<td>17.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP</th>
<th>TRIAC #</th>
<th>Stud Size</th>
<th>Foot Print</th>
<th>P.C. c.f.w</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>T8410 (D0)</td>
<td>1/2-20</td>
<td>1.0&quot; dia</td>
<td>.35</td>
</tr>
<tr>
<td>20</td>
<td>T8411 (D0)</td>
<td>1/2-20</td>
<td>&quot;</td>
<td>.35</td>
</tr>
<tr>
<td>10</td>
<td>T6420 (J-1)</td>
<td>1/4-28</td>
<td>.540 dia</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>T6411 (H-1)</td>
<td>1/4-28</td>
<td>.540 dia</td>
<td>.9</td>
</tr>
<tr>
<td>1</td>
<td>2N5574 (H)</td>
<td>1/4-28</td>
<td>.540 dia</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Determining the maximum heat sink temperature in all of the above cases—

Assume \(T_{\text{Junction}} = 150^\circ\text{C}\) \text{max.}
a) 30 HP Case
Assume 1/2"-20 stud is torqued to 125 in-lb min & that silicone grease and a .002" THK mica washer is used at the interface

\[
\text{Contact area} = \frac{\pi}{4} \left[ \frac{4}{2}^2 - \left( \frac{1}{2} \right)^2 \right] = \frac{\pi}{4} \left[ 1.0^2 - 0.5^2 \right] = 0.571 \text{ in}^2
\]

\[
K_{\text{mica}} = 0.34 \frac{\text{Btu}}{\text{in}^2 \cdot \text{hr} \cdot \circ\text{F}} \quad (0.0247 \text{ THM})
\]

\[
K_{\text{silicone grease}} = 0.15 \frac{\text{Btu}}{\text{in}^2 \cdot \text{hr} \cdot \circ\text{F}} \quad (0.0013 \text{ THM})
\]

\[
\Sigma R_{\text{contact}} = R_{\text{mica}} + R_{\text{silicone grease}}
\]

\[
= 0.002 (44)(0.44) + 2 \left[ -0.001(17.7)(3.5) \right]
\]

\[
\left( 12 \right)(0.34)(0.54)(0.4) \left( \frac{145}{12} \right)(0.59)
\]

\[
R_{\text{contact}} = 0.23 + 0.17 = 0.40 \circ\text{F}/\text{watt}
\]

\[
\Delta T = QR = 155.6 (35) = 54.5 \circ\text{C}
\]

\( (\text{junction to case}) \)

\[
\text{Heat sink max} = 150 \circ\text{C} - 54.5 \circ\text{C} - 0.40 (0.55%) = 73.26 \circ\text{C}
\]
The 35.26°C heat sink temperature (maximum) is less
than the maximum inlet
air temperature of 140°F (60°C).

Therefore two diodes will be
required in parallel in each leg.

\[ \text{Heat sink temperature (max.)} = 150^\circ \text{C} - \frac{Q_{SR}}{2} \]

\[ = 150 - \frac{155.6 \cdot [0.35 + 0.40]}{2} \]

\[ = 91.65^\circ \text{C} \ (196.9^\circ \text{F}) \]
$T_{air} = 140^\circ F = 60^\circ C \text{ (max.)}$

Considering an IERC style heat exchanger - Type E2

$2\frac{3}{8}'' \pm \frac{1}{32}''$ (Type E2)

Cross sectional area = 

\[ 0.185 \left[ 4.5 - 2.43 \right] + (2.5 - 1.85) \times (0.09) \times 0.8 \]

= 2.34 in$^2$

Weight per foot length = (2.34)(60)(0.5)

= 280 lbs/foot

The perimeter of the section is

\[ 2 \left[ 4.5 - 2.43 \right] \times 2 + (2.5 - 1.85) \times 16 = 44 \text{ in.} \]

\[ Q = 15 \text{ hr} \times A \times \text{Tanh mL} \]

\[ Q = \text{power} = \frac{155.6 \times (3.41)}{4} = 132.65 \frac{\text{Btu}}{\text{hr}} \]

\[ m = \sqrt{\frac{hc}{\delta A}} \]
\[ h = \text{film coeff.} - \frac{\text{BTU}}{\text{hr} \cdot \text{ft}^2 \cdot \text{OF}} \]

\[ C = \text{Perimeter of the finned section} = 44 \text{ inches} \]

\[ A = \text{Cross sectional area of the finned section} = 0.34 \text{ in}^2 \]

\[ L = \text{one half of the length of the finned heat exchanger} \]

\[ \theta_0 = T - 14 \text{ (OF)} \]

Assume that a Rotron Muffin type fan is used \& \( q_{\text{cfm}} = 90 \text{ cfm/h} \).

Calculating the Temperature Rise of the air through the enclosure at 466.8 watts dissipation \& 90 cfm inlet air at 140°F:

\[ \theta_h = \frac{\text{cp} \cdot \Delta T}{140°F} \]

\[ \text{at } 140°F \quad \text{(\( \text{cp} = 0.0661 \))} \]

\[ \frac{24 \text{ BTU}}{16 \text{ OF}} \]

\[ (466.8)(3.41) \frac{\text{BTU}}{\text{hr}} = \frac{90 \text{ ft}^2 \cdot \text{min} \cdot \text{OF}}{60 \text{ min} \cdot \text{hr} \cdot \text{BTU} (0.0661) \text{ hr}} \]
\[ \Delta T_{op} = \frac{466.8 (3.41)}{20 \times 60 \times 0.066} = 18.6 \,^\circ F \]

\[ T_{mean} = \frac{140 \,^\circ F + 18.6 \,^\circ F}{2} = 149.3 \,^\circ F \]

\[ \Delta T = T - T_{f} = 196.9 - 149.3 = 46.7 \,^\circ F \]

\[ \text{Velocity} = \frac{\Delta T_{op} \times 30 \,^\circ F}{16 \times (4.5)^2} = 640 \,\text{ft/min} \]

\[ \text{Reynolds Number (Re)} = \frac{V \times L}{\mu} \]

Assume \( L = 3.0 \,^\prime \)

\[ T_{f} = 150 \,^\circ F \]

\[ \rho = 0.0650 \,\text{lb/ft}^3 \]

\[ \mu = 0.0495 \frac{16}{1 \times 0.0170 \,\text{lb-ft}} \]

\[ N_{re} = \frac{640 \times 60 \times (3^2) \times 0.065}{12 \times (0.0495)} = 1.26 \times 10^4 \]

Therefore the flow is laminar and the following equation is applicable:
\[ h = \frac{K}{L} (-664) (\text{NPR})^{-2} (\text{NPR})^{\frac{1}{3}} \]

NPR @ 150°F = 0.7

\[ h = \frac{-0.070 (12) (-664) (1.26 \times 10^4)^{0.5}}{3} \]

\[ h = 4.50 \frac{\text{BTU}}{\text{hr} \cdot \text{ft}^2 \cdot \text{°F}} \]

\[ m = \frac{\sqrt{\frac{h \cdot c}{5.4}}}{\sqrt{\frac{(4.5)(94)(90)(2.34)}{(12)(90)(2.34)}}} = 3.359 \]

Substituting in equation #1

\[ Q = k M A \theta \ \text{Tanh} \ \text{Cm} \]

\[ \frac{153.6 (3.41)}{4} = \frac{(90)(3.359)(2.34)}{144} (46.3) \ \text{Tanh} [3.3] \]

\[ \text{Tanh} [3.3592] = 0.578 \]

\[ 3.3591 = \text{Tanh}^{-1}(0.578) = 0.659 \]

\[ L = 0.196 \text{ ft} = 2.357 \text{ inches} \]

or Total Length Reqd = 0.3357

\[ = 4.71" \ \text{in} \] (Two reg'd per 65)
Summarizing the applicable eqns. and incorporating the constants for 140°F inlet air:

2. \[ \Delta T_{cof} = \frac{3.503 \, \text{in}^2}{Q_{cfm}} \]
   where:
   \( \Delta T \) = Rise in cooling air Temp.
   \( \text{in}^2 \) = Total power dissipation in the enclosure
   \( Q_{cfm} \) = fan flow rate

3. \[ \text{Reynolds No. } \frac{V_{cfpm}}{W} = \frac{(V_{cfpm}) (L \text{ inc hor}) (0.66) (6)}{12 (0.0495)} \]
   \[ \left[ \text{Reynolds No. } = 6.678 \, (V_{cfpm}) (L \text{ inc hor}) \right] \]
   For laminar flow:
   \[ h = \frac{5}{2} (0.664) \left( \frac{\text{NRE}}{\text{NPR}} \right)^{\frac{1}{3}} \]
   \[ h = (0.0170) (0.664) \left( \frac{\text{NRE}}{\text{NPR}} \right)^{\frac{1}{2}} (C) \]

4. \[ h = 0.120 \left( \frac{\text{NRE}}{\text{NPR}} \right)^{\frac{1}{2}} \]
\[ Q = 15 \text{ M A} \theta_0 \tanh (\text{mL}) \]

Where \( m = \sqrt{hc \over 5A} \)

\( \theta = 46.7 \degree \text{F (max)} \)

For an aluminum section:

\[ X = 90 \text{ Btu/min-ft}^2 \text{-OF/ft} \]

\[ m = \sqrt{hc \over (2)(90)(A)} = \sqrt{132hc \over A} \]

\[ Q_{\text{watts}} \quad (3.41) = 90 \text{ M A}^2 \left( {46.7 \over 144} \right) \tanh (\text{mL}) \]

\[ \left[ \tanh (\text{mL}) = {1167Q_{\text{watts}}} \over m(A^2) \right] \]

Where \( Q_{\text{watts}} = \text{one half the power dissipated on the heat exchanger} \)

\( L = \text{one half the required length in feet.} \)
Assuming a 6" box and one Rotron fan (Q = 90 cfm)

E500 heat sink section = 3" long

A = 2.142 in² (C = 48.1 in. perimeter)

\[
V = \frac{Q}{A} = \frac{90}{(6 \times 4.7 - 2(2.142))} = 5.42 \text{ ft/min}
\]

\[
N_r = 6.628 \frac{V}{L} = 6.628(5.42)(3) = 1055 \times 10^4
\]

\[
h_c = \frac{(120)(1.085)\frac{1}{2}}{3} = 4.17
\]

\[
m = \sqrt{\frac{.133}{A}} \frac{h_c}{A} = \sqrt{\frac{.133(4.17)(4.8)}{2.142}}
\]

\[
m = 3.529
\]

\[
\text{Tanh} \ (mL) = -1.16 \frac{Q}{mA}
\]

\[
\text{Tanh} \ (3.529L) = -1.16 \left( \frac{15.6}{3.529} \right) = 0.601
\]

\[
3.529L = \text{Tanh}^{-1} 0.601 = 0.6948
\]

\[
L = 0.197 \text{'}
\]

.. Total length = 0.197 × 2 × 12 = 4.75

Box length (min) = (4.75)(2) + 1.5 = 11.5 ≈ 16"
Fan & Heat Exchanger Volume:
6" x 16" x 4.25" - 30 HP (240V)
Six heat sinks required (3 on the Top, 3 on the Bottom)
Using heat sink style E520
With Two Muffin fans in parallel,

\[ V = \frac{Q}{A} = \frac{90 \times 2 (144)}{[(6)(4.7)(3) - 4(0.1423)} \]

\[ M = 3.529 \] (no change)

\[ L = 4.73" \text{ min for each heat exchanger} \]

\[ \text{Length} = 1.5 + 4.75 (2) = 11'' \min \]

\[ (130 \times 6'' \times 11'' \times 9.20) \]

Six Heat Exchangers again required.
Four mounted on the base, two on the cover.
Considering the E615 section

Heat sink - \( A = 3.425 \text{ in}^2 \)

\( C = 71.4 \text{ inches per minute} \)

Assume \( L = 2.5 \) - Two Fans in parallel

\[ V = \frac{(60 \times 2)(144)}{(6)(4.7)(2)(3.425)} = 522 \text{ fpm} \]

\[ N_r = 6.67 \times V \times L = (6.67)(522)(2) = 6945 \]

\[ h_c = -100 \sqrt{\frac{C}{N_r}} = -100 \sqrt{6945} = 4.01 \]

\[ m = \sqrt{\frac{133 h_c}{A}} = \sqrt{\frac{(133)(4.01)(744)}{3.425^2}} = 3.335 \]

\[ \tan h_c = \frac{1160 \times 2}{1244} \]

\[ \tan h_c = \frac{(1160)(157.6)}{4 \times (3.325)(3.425)} = 3.958 \]

\[ 3.335 \times L = 42.2 \]

\[ L = 12.67 \]

\[ L_T = (12.67)(6)(12) = 3.04 \text{”} \]

- Could use Two muffin fans.

Six heat sinks (3” x 3” x 3”). Box size

24” x 12” x 12” = 0.711 x 11 x 11 x
30 HP, 440 Volt Case

\[ E'_{\text{th}} = E_2 - \alpha + R_{\text{case}} \rightarrow \mu \]
\[ = 0.35 + 0.40 = 0.75 \text{ \degree C/m} \]

\text{(as before)}

\text{Power dissipation} = \frac{1556}{2} = 778 \text{ watts per leg}

\text{Assuming a 150 \degree C max Junction Temperature - (Ambient) = 140 \degree F}

\text{Heat sink} = 150 \degree C - Q \text{ ERP} \max
\[ = 150 \degree C - (27.8) (75) = 91.65 \degree C \]

\text{(196.9 \%)}

\text{Assume one diode and heat exchanger per leg - All flow rate parameters are the same per heat exchanger as in the prior case -}

\[ \text{\# ESP0 Heat sink} \]
\[ 4.75 " \text{ long} - \]
\[ \text{Three legs} - \]
\[ \text{on the base, one on the cover} - \]
\[ 7.2 " \text{ \# FH15 base mounted} \]
III 20 HP - 240 V Case

Power per leg = 108.7 watts

\[ E_{\text{thermal}} = P_{\text{r-c}} + P_{\text{case}} \text{ in watt} \]
\[ = 0.85 + 0.4 = 1.25 \text{ °C/watt} \]

Same case size & r-c as in the 20 HP instance.

Heat sink = 150 °C - \( E(R) \) (max)
\[ = 150 °C - (0.7)(75) = 72.5 °C \]
\[ = 162 °F \]

\[ Do = T_h - T_{\text{air}} = 162 - 140 = 22 °F \]

Considering E 615 Heat Sink
\[ A_p = 3.425 \text{ in}^2 \]
\[ C = 71.4 \]

Two fans in parallel
\[ V = \frac{Q}{A} = \frac{50(2)(144)}{(6)(47)(70) - 2(3.425)} = 523 \text{ fpm} \]

Assume \( L = 4'' \)

\[ \frac{N/\pi}{L} = \frac{6.67 \pi VL}{(523)(3)} \]
\[ = 13970 \]
\[ h_0 = \frac{100}{4} \left( \frac{12 - 0}{12 - 0.5} \right)^{1/2} = 3.54 \text{ ft} \]

\[ m = \sqrt{\frac{100 \times 0.5}{A}} = \sqrt{\left( \frac{100 \times 0.5}{A} \right) \left( \frac{12 - 0.5}{12 - 0.5} \right)} \]

\[ m = 3.130 \]

\[ Q = 5 \times m \times A_0 \times \text{Tanh} \left( \frac{mL}{2} \right) \]

\[ \frac{100 \times 0.5}{2} = (3.130) (12 - 0.5) \left( \frac{3.130}{2} \times 12 \right) \left( \frac{y}{2} \right) \left( \text{Tanh} \left( \frac{mL}{144} \right) \right) \]

where \[ mL = (3.130) \left( \frac{y}{2} \times 12 \right) \]

\[ \theta_0 = 54.99^\circ \text{F which is in excess of the 22^\circ \text{F allowable}} \]

Assume \# 4005 section heat sink \[ A_v = 4.325, \ C = 81.9 \text{ in}^2/\text{in} \]

\[ V = \frac{Q}{A} = \frac{(3.130)(3.130)(0.5)}{(6)(10 - 2(3.325))} = 504 \frac{\text{ft}^3}{\text{min}} \]

Assume a 6” length -

\[ l = 6.67 + V \times L = 6.67 \times (504)(6) \]

\[ = 20,150 \]
\[ h_c = \frac{120}{7} \sqrt{4\pi} \]
\[ = \frac{120}{7} \sqrt{4\pi} \]
\[ \approx 2.842 \frac{\text{BTU}}{\text{hr}-\text{F}^2 \text{of}} \]

\[ m = \frac{\sqrt{1.133 h_c C}}{A_s} = \frac{\sqrt{(1.133)(2.842)(4.19)}}{4.325} \]
\[ = 2.625 \]

\[ \theta_0 = 41.85^\circ F \]

\[ \frac{10.73}{2} (3.41) = (90)(2.625)(4.325) \theta_0 \text{Tanh} \left[ \frac{2.625x}{2} \right] \]

\[ \theta_0 = 41.85^\circ F \]

Which would result in a function:

\[ \text{Temperature of } 150^\circ F + \frac{41.85 - 22}{1.8} = 161^\circ C \]

If \( L = 7'' \) (same H.S.)

\[ \frac{8.67 \pi}{2} = \left( \frac{8.67 \pi}{2} \right)(504)(7) \]
\[ = 23,575 \]

\[ b_c = \frac{120}{7} \sqrt{4\pi} \frac{(1.133)(2.625)(4.19)}{2.625} \]
\[ = 2.63 \]

\[ m = \sqrt{\frac{1.133 h_c C}{A_s}} = \sqrt{1.133(2.63)(4.19)} = 2.574 \]
\( Q = 15 \text{ MHA} \theta_0 \text{ Tank cm}^2 \)

\[
\left( \frac{103.7}{2} \right) (3.4) = (\theta_0) (2.674) (4.325) \theta_0 \text{ Tank} \left( \frac{2.074(12)}{24} \right)
\]

\[ \theta_0 = 39.98 ^\circ F \]

\[ T_g = 180 ^\circ C + 39.98 - 22 \times \frac{1.8}{1.8} = 159 ^\circ C \]

If the 159\(^\circ\)C junction temperature is unacceptable - then two cooler per leg will be required and the smaller heat exchanger could be used - The box size for the E601 H.S. (3 reg'd each 7" long) would be 6" x 10" x 16" for cooling volume -

Consider two cooler per leg,

6 heat sinks of the E615 type 3" long - \( A_r = 3.425 \) \( C = 71.4 \text{ in}^3/\text{min} \)

Two fans

\[ V = \frac{Q}{A} = \frac{(\theta_0) (2) (144)}{\left[ (6) (4.25) (2) - 2 (3.425) \right]} = 517 \text{ ft}^3/\text{min} \]
\[ T_{\text{HSHC}}(\text{cmol}) = \frac{T_j - Q(E)}{150^\circ C - (51.9)^{C/2}} = 111.08^\circ C \]
\[ \Theta_0 = 232 - 140^\circ F = 91.9^\circ F \]
\[ h_c = \frac{1200 (\text{cmol})^{-1/2}}{2} \]
\[ N_c = (6.67 \times 10^3) V_L = (6.67 \times 10^3) (51.7) \times 3 = 10356 \]
\[ h_c = \frac{-1200 (19356)^{-1/2}}{3} = 4.07 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ F} \]
\[ m = \sqrt{\frac{1.133 h_c C}{A}} = \sqrt{\frac{(1.133)(4.07)(31.4)}{3.425}} = 3.3592 \]
\[ Q = 15 \text{ m } A \Theta_0 \text{ Tenh } (\text{cmol}) \]
\[ \left( \frac{51.9}{2} \right) (3.41) = 90 (3.3592)(3.425) \Theta_0 \text{ Tenh} \left[ \frac{3.3572 \times 10^{-6}}{1.44} \right] \]
\[ \Theta_0 = 31.00^\circ F \]
\[ \text{Which is much less than required.} \]

Assume two choker per line again using H.S. section E102 - 1.5" long
\[ A_r = 1.792 \text{ in.}^2 \]
\[ C = 3827 \text{ in.}^2/\text{in.} \]
\[ \& \text{ one fan} \]
\[ V = \frac{Q}{A} = \frac{(20)(144)}{6}(4.25) = 45.4 \text{ cfm} \]

\[ N_R = 6.62 P V L = (6.678)(454)(1.5) = 45.47 \]

\[ h_c = \frac{120}{2} (N_R)^{1/2} = \frac{120}{1.5} (4547)^{1/2} = 5.39 \]

\[ M = \sqrt{\frac{133 h_c}{A}} = \sqrt{\frac{(133)(5.39)(362)}{1292}} = 3.9346 \]

\[ Q = \frac{5}{4} M A \theta_0 \tan h (cm^2) \]

\[ \left( \frac{5.19}{2} \right) (3.41) = (20)(3.9346)(1.792) \theta_0 \tan h \sqrt{3.9346} \]

where \( L = \frac{1.5}{D} \)

\[ \theta = 53.3^\circ F \]

- The six 1 1/8" long section \# E102 is acceptable — one
  - Motion must be Type FDR required.
  - Box size 6" x 11" x 4.98"

IV 20 HP - 440 Volt per leg
  - With one diode per leg,
  - Each diode dissipating 51.9 watts.
The previous heat sink (1.5" long, #E102 section) & one fan will result in an acceptable Diode Junction temperature. I.e. These heat sinks will be required in this case - but size for cooling provisions will be 6" x .5" x 4.75"

V 10 HP - 240 V per leg
\[ R_{2-c} = 1.0 \text{ ohms} \]

Contact area: \[ \frac{D_e^2 - D_a^2}{4} \]
\[ D_e = .5" \text{ dia} \quad D_a = \frac{1}{4}" \text{ dia} \]

\[ A_c = \frac{\pi}{4} \left[ .5^2 - .25^2 \right] = .1875 \text{ in}^2 \]

\[ \Sigma R_{th} = R_{mica} + R_{silicone} \]
\[ \text{contact area} = .002" \text{ thick} \quad \text{spec 1 = .001" thick} \]

\[ \Sigma R_{th} = \Sigma \frac{L}{A} \]

\[ = \frac{.002 (144)(5.41)}{(12)(.034)(.1875)(144)} + 2\left[ \frac{1.001 (144)(2.41)}{(12)(.045)(.1075)(144)} \right] \]
\[ P_{eh} = 0.71 + 0.54 = 1.25 \text{ \textdegree C/mW} \]

This number appears to be a bit high. Telecon with RCA resulted in a value of 1.0 \textdegree C/mW

\[ \therefore \text{Heat sink }_{\text{max}} = 180^\circ C - Q(\text{ER}) \]

\[ = 150^\circ C - 51.8\text{ W} (20 + 10)^2/\text{W} \]

\[ = 46.4^\circ C (115.52^\circ F) \]

The maximum heat sink temperature is less than the 140^\circ F inlet cooling air. Therefore, two diodes per line will be required.

Power per diode = \[ \frac{51.8}{2} = 25.9 \text{ mW} \]

with two diodes per leg (240V)

\[ \text{Heat sink } = 150^\circ C - 25.9^\circ C (2) = 97.2^\circ C \]

\[ = 211.2^\circ F \]

\[ \Theta_d = \Theta_{hr} - \Theta_{mr} = 211.2^\circ F - 140^\circ F = 71.2^\circ F \]

Considering a E101 section heat sink - A - 1000 cm^2 = 26.9 inch perimeter
\[ V = \frac{Q}{A} = \frac{90 \text{ (Circ.)}}{6 \text{ (4.25) \ (Conc. fan)}} = 45.4 \text{ ft./min} \]

\[ \text{NR} = 6.67 \text{ Plvl} = 6.878 \text{ (454) C} \text{ (5)} \]
\[ \text{EL} = 1.5'' \]

\[ \text{NR} = 4548 \]

\[ \text{hc} = \frac{120 \text{ (NR)}}{L} = -132 \text{ (4548)} = 5.39 \]

\[ M = \sqrt{\frac{133 \text{ hc}}{A}} = \sqrt{\frac{(133)(5.39)(26.9)}{1.058}} = 4269.3 \]

\[ \theta = 5.5 \text{ M} \text{ A} \theta \text{ Tanch (Conc.)} \]

\[ \left(\frac{25.9}{2}\right)(3.41) = \left(\frac{52}{4269.3}\right)(1.058) \text{ Tanch} \left[\frac{4269.3 \times 144}{144}\right] \]

\[ \theta = 60^\circ \text{F} \quad \text{which is acceptable} \]

Therefore - for the 10 HP, 240V condition use a checker per leg, each with a # E701 section, 1.5'' long.

Box size for cooling - Cone fan

6'' x 11'' x 4.75''

or 6'' x 8'' x 4.75'' if three or

The heat sinks are mounted on the
10 HP - 415 Volt per leg
With one unit per leg, the power dissipation is 25.9 watts per unit. From the prior calculations, three heat sinks will be required (Type E101, 1/2" long).
One Form Box Size 6" x 8" x 4.5"
For cooling components.

5 HP - 240 Volts per leg
Power dissipation per leg is 29.6 watts.

\( R_{c-e} = 0.06/\mu \)

\( R_{c-heat sink} = 1.0 \degree C/watt \) (Ref RIR)

\( T_{heat sink} = 150\degree C - Q(ER) \)
(\( T_{max} \))

\( = 155\degree C - 29.6(1.0 + 0) \)

\( = 93.76\degree C \) (200.7°F)

\( T_o = T_{env} - T_f = 200.7\degree F - 140\degree F = 60.7\degree F \)
(Min)
Assuming one Muffin Type for and a #E101 Type Heat sink
1 1/2" Long - From the calculations presented in Section II
V = 454 ft/min, HR = 454 ft
HC = 5.29, M = 4.2693
Q = 5 m A & Tank (cont)

\[
\left(\frac{29.6}{2}\right) \times (3.41) = 90 (4.2693) (1.05) \frac{\theta_0}{\text{Tank}} \left[ \frac{4.2693 (6.5)}{144} \right]
\]

\[
\theta_0 = 61.5 \, ^\circ F
\]

Which exceeds the 60.7 Max

Allowable -

\[
\theta_{ij} \quad L = 2''
\]

\[
HC = \frac{-120}{L} (HR)^{1/2}
\]

\[
HR = \frac{6.67PVL}{L} = 6.67 (454) (2) = 6064
\]

\[
HC = \frac{-120}{5} (6064)^{1/2} = 4.672
\]

\[
M = \sqrt{\frac{133HC}{A}} = \sqrt{\frac{(133)(4.672)(26.9)}{1.05}} = 3.974
\]
\[ Q = 15 \text{M A} \theta_0 \tanh (cm) \]
\[ \frac{Q}{29.6} \left( \frac{3.41}{2} \right) = (30)(3.974)(1.05) \theta_0 \tanh \left( \frac{3.974 \theta_0}{2} \right) \]

\[ \theta_0 = 60.05 \text{ which is acceptable} \]

- The 2" long E101 section is acceptable - one heat sink per diode - (E muffin type fan)

- Box size - 6"x8"x4.5" for cooling components will be required

Considering a Free convection

System and assuming an E615 Type section, \( C = 71.4\) in, \( A_t = 3.425 \)

\( L = 2"\) long -

Assume \( \Delta T_{\text{F}} = 60^\circ\text{F} \)

\[ h_c = 0.29 \left( \frac{\Delta T}{L} \right)^{1/4} \text{ for vertical plate} \]

\[ h_c = 0.29 \left( \frac{60}{3} \right)^{1/4} = 1.14 \text{ Btu} \frac{\text{hr}}{\text{ft}^2 \cdot \circ\text{F}} \]

\( Q = h_c A_t \Delta T \)

\[ 29.6 (3.41) = (1.14) \left( \frac{A_t}{14.4} \right) (60) \]
\[ A_{\text{min}} = 212.5 \text{ in}^2 \]

\[ C = 21.4 \quad L = 3'' \]

\[ C_2 = (21.4)(3) = 64.2 \text{ in}^2 \]

which is about equal to the 212.5 minimum area reqd.

- Could use no fan and
- Three 3'' sections of #E65
  (One per chode) and mounted
  vertically in the 3'' channel
  Box size = 6'' x 9'' x 4.25''

\[ \text{VIII} \quad 5 \text{ HP - 440V condition} \]

Power dissipation per leg = 14.56 W

\[ R_{y-c} = 900 \text{ k} \Omega \quad j R_{e-m} = 10 \text{ k} \Omega \]

\[ \text{Heat sink} = 150^\circ C - Q(ER) \]

\[ \text{max} = 150^\circ C - (34.5)(10 + 9) \]

\[ = 121.85^\circ C (251 - 34^\circ F) \]

\[ \Theta = T_{hs} - T_f = 251.4 - 140 = 111.4^\circ F \]

Assuming a 3'' long fin -
\[ h_c = -29 \left( \frac{A_1}{L} \right)^{1/4} = -29 \left[ \frac{111.4}{1752} \right]^{1/4} \]

\[ = 1.33 \frac{\text{Btu}}{h_a - f_t^2 \cdot \varphi} \]

Assuming an E102 section \( L = 2'' \)
\( C = 38.7 \quad A_a = 1752 \)
\( \varphi = h_c A_a A_t \)

\[ (L \cdot \varphi)(C.41) = (1.33)(\frac{A_1}{144})(111 \, \circ F) \]

At min. regd = 43.2 in.
\( C_L = 38.7 (3'') = 116.1'' \) which is more than required.

Trying a 1.5'' long section - #E101
\( C = 26.9 \)

\[ h_c = -29 \left( \frac{111}{15} \right)^{1/2} = 1.58 \frac{\text{Btu}}{h_a - f_t^2 \cdot \varphi} \]

\[ (L \cdot \varphi)(C.41) = (1.58)(\frac{A_1}{144})(111 \, \circ F) \]

At min. regd = 41.4
\( C_L = 26.9 (1.5) = 40.35 \)

which is very close to the 41.4 min.

End of text.
Radiation was not considered in the analysis.

- Three heat sinks, one per diode, vertically mounted, of the "E 101 section - 1.5" long will be required.

Box size = 4" x 5" x 4.5"

For cooling components:

\[ \text{XI} \]

1 HP - 240V per leg

Power Dissipation per leg = 5.93 kW

\[ R_e - c = 1.0 \text{ ohm} \quad R_e - h_p = 60 \text{ ohm} \]

\[ T_{heat sink} = 150^\circ C - \Theta (\text{ER}) \]

\[ (\text{min}) = 150^\circ C - 5.93(20 + 10) \]

\[ = 130.14^\circ C \]

\[ \Theta = T_{heatsink} - T_f = 150 - 140 = 140^\circ F \]

For a vertical plane surface -

\[ h_c = 0.29 \left( \frac{AT}{L} \right)^{1/4} = 0.29 \left( \frac{140 \cdot 12}{6} \right)^{1/4} \]

Assuming \( L = 6'' \)
Assume that the plate geometry is such that

\[ A_s = 1.25 \quad \text{and} \quad C = 6 \]

\[ m = \sqrt{\frac{1.73 \cdot 6}{A}} = \sqrt{\frac{(132)(1.133)(6)}{1.25}} = 1.123 \]

\[ E = 5 \text{ in} \quad A \quad \theta_0 \quad \text{Tanh} (mL) \]

\[ L = \frac{3}{12} = .25 \]

Assume also that all three sides are mounted on the same plate:

\[ \frac{(5.93)(3)(2.41)}{2} = \frac{(90)(1.133)(6.75)}{144} \quad \theta_0 \quad \text{Tanh} \left( \frac{100}{144} \right) \]

\[ \Theta_0 = 210.6 \text{ }^\circ \text{F} \quad \text{which exceeds} \]

The \( \Theta = 140 \text{ }^\circ \text{F} \) max allowable –

If radiation to a 140\(^\circ\)F environment is considered –

Assume that \( T_{\text{HF}} = 240 \text{ }^\circ\)F \( (700 \text{ }^\circ\)K) and \( T_{\text{ambient}} = 140 \text{ }^\circ\)F \( (600 \text{ }^\circ\)K)
$$h_r = 0.1714 \times 10^{-2} \times Fe \cdot Fa \left[ \frac{T_1 + T_2}{100} \right] \left[ \frac{T_1^2 + T_2^2}{200} \right]$$

Assume \( Fa = 10 \) & \( Fe = 0.9 \)

$$h_r = (0.1714 \times 10^{-2}) \times 9 \left[ \frac{700}{100} + \frac{600}{100} \right] \left[ \frac{700^2}{200} + \frac{600^2}{200} \right]$$

$$h_r = 1.20$$

$$h = h_c + h_r = 1.186 + 1.20 = 2.386$$

$$h_0 = \frac{h}{h_r}$$

$$m = \sqrt{\frac{1.33 h_c c}{A}} = \sqrt{\frac{(1.33)(2+3)(6)}{2}}$$

$$Q = 15 m A \Theta_0 \tan h (\text{mol})$$

$$\frac{(5.93)(3)(0.41)}{2} = 90 \Theta (1.7536)(0.75) \tan h \left[ \frac{1.7536}{144} \right]$$

$$\Theta_0 = 89 \text{ of which it last}$$

Then the \( \Theta = 140^\circ \text{F max allowable} \)

$$T_x = .25 = T_f + \frac{T_x - T_f}{\text{Cosh} hL}$$

Since from the above \( \Theta_0 \) is

\( T_x = 8^\circ \text{F range at } 15^\circ \text{F to } 140^\circ \text{F} \)
Assume $T_0 = 100^\circ F$, i.e. $T_0 = 370^\circ F$

$T_x = \phi' = 140^\circ F + \frac{100}{\cosh(1.43 \times 25)}$

Assuming $M = \frac{1.123 + 17536}{2} = 173$

$T_x = \phi' = 140^\circ F + 93.9 = 233.9^\circ F$

- The temperature gradient is minimal in the z direction ($240 - 233.9 = 6^\circ F$)

Assuming $T_0 = 80^\circ F$

i.e. $T_{hs} - T_f = 80^\circ F$

$T_{hs} = 115 + T_f = 80 + 140 = 220^\circ F$

$h_c = 0.29 \left( \frac{4T}{L} \right)^{0.4} = (0.29) \left[ \frac{80}{6} \right]^{0.4}$

$h_c = 1.03 \text{ BTU/hr ft}^2^\circ F$

$T_{hs} = 220 \ (680^\circ R) \ T_a = 140^\circ F (600)^R$

$h_r = 0.1714 \times 10^{-2} \times \frac{6.8 + 6}{6.8^2 + 6^2}$

$h_r = 1.624 \text{ BTU/hr ft}^2^\circ F$
\[ h_T = h_R + h_c = 1.624 + 1.03 = 2.654 \]
\[ m = \sqrt{\frac{1.35 h_c c}{A}} = \sqrt{\frac{(1.35)(2.654)}{6}} = 1.680 \]
\[ Q = 5\, m\ A\ \theta_0 \ \text{Tank \ (in\)} \]
\[ \left( \frac{5.93}{2} \right)^2 = 5.93 \cdot 1.610 \ \text{Tank} \left( 1.610 \times 2 \right) \]
\[ \theta_0 = 97 \]
\[ \therefore \theta_0 \ is \ in \ the \ range \ of \ 75\ \text{F to 97°F} \]
\[ T = 97°F \]
\[ \therefore \ \text{max} = 140 + 97 = 237°F \ (117°C) \]
\[ T_{\text{function}} = 114°C + Q(E_Rth) \]
\[ = 114°C + 5.93(20) \]
\[ = 125°C \ \text{which is acceptable} \]
\[ \therefore \ \text{heat sink for the 1 HP} \]
\[ 240 \ V (\& 415V) \ \text{condition should be a 6" x 6" x 1.05" thick plate} \]
\[ \text{anodized per MIL-A-8625 Type I} \]
\[ \text{Cylindrical block - The Three} \]
Admiral should be mounted in the center of the plate.
Summary of the Heat Exchanger Configurations

I

1 HP - 240V 450V
Free Convection - Flat Plate 6"x6" x.125" THK (Aluminum) Black on side

II

5 HP
a) 480 VOLT - Free Convection IERC section # E101 - 15" Long - one per diode per heat sink - Box size 4"x5"x45" (for cooling only)
b) 240 VOLT
1) Free Convection - Three 3" sections # E615 mounted vertically - Box size 6"x4"x4"
d) Forced convection
   Three #E101 sections
   Each 3" long & one
   Muffin fan - Box Ge
   6" x 6" x 4.75"

III

10 HP

a) 480 volts - Three Type
   E101 heat sinks 17/8" long
   One Muffin fan
   6" x 6" x 4.75"

b) 240 volts - Use two
   diodes per leg, one
   heat sink per diode,
   Section #E101 - 15" long
   One Muffin Type fan
   Box size 6" x 11" x 4.75" or
   6" x 8" x 4.75" if the heat
   sinks are mounted to the
   cover
30 HP

a) 480 Volt - one diode per leg, three heat sinks, type E102, 15" long, box size 6" x 10" x 4.25" - one muffin fan

b) 240 Volt - two diodes per leg, 6 heat sinks, 15" long type E102 - one muffin fan, type fan - box 6" x 10" x 4.25"

c) 240 Volt - one diode per leg, three heat exchangers, type E605, 7" long, two Potron fans - box size 6" x 10" x 16"
Type # E520 Type sections
4.75" Long - Two on the base
one on the cover -
box size - 6" x 11" x 4.75"

b) 240 volt - Two diodes per leg - Two fans
Six heat exchangers Type
# E520 - 4.75" Long
Box 5gc - 6" x 11" x 9.5"
## APPENDIX L

### ENERGY SAVINGS

<table>
<thead>
<tr>
<th>HP</th>
<th>EFF (w/o MCR)</th>
<th>($/yr)</th>
<th>EFF (w/ MCR)</th>
<th>($/yr)</th>
<th>Δ in $/yr</th>
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<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>FL</td>
<td>0.650</td>
<td>$137.72</td>
<td>0.700</td>
<td>$127.89</td>
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<tr>
<td>3/4L</td>
<td>0.550</td>
<td>162.76</td>
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<td>223.80</td>
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<td>162.76</td>
<td>61.04</td>
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<td>298.40</td>
<td>0.500</td>
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<td>NL</td>
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<td>596.80</td>
<td>0.400</td>
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**Average:** $117.65/yr

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<th>EFF (w/o MCR)</th>
<th>($/yr)</th>
<th>EFF (w/ MCR)</th>
<th>($/yr)</th>
<th>Δ in $/yr</th>
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<td>91.82</td>
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<td>895.20</td>
<td>0.650</td>
<td>688.62</td>
<td>206.58</td>
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<td>1,119.00</td>
<td>0.600</td>
<td>746.00</td>
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<tr>
<td>NL</td>
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<td>2,238.00</td>
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<td>994.67</td>
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**Average:** $390.04/yr

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<th>EFF (w/ MCR)</th>
<th>($/yr)</th>
<th>Δ in $/yr</th>
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<td>0.825</td>
<td>2,170.18</td>
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**Average:** $687.00/yr

IVECO INC.

IMPROVEMENT VIA ELECTRONIC
## Energy Savings

### 50 HP

<table>
<thead>
<tr>
<th>Eff (w/o MPA)</th>
<th>(MPC) in $/yr</th>
<th>Eff (w/ MPA)</th>
<th>(MPC) in $/yr</th>
<th>Δ in $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.875</td>
<td>5,115.43</td>
<td>0.875</td>
<td>5,115.43</td>
</tr>
<tr>
<td>3/4L</td>
<td>0.800</td>
<td>5,595.00</td>
<td>0.850</td>
<td>5,265.68</td>
</tr>
<tr>
<td>1/2L</td>
<td>0.650</td>
<td>6,886.15</td>
<td>0.730</td>
<td>6,713.37</td>
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<tr>
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<td>0.620</td>
<td>7,219.35</td>
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<tr>
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<td>0.350</td>
<td>12,788.57</td>
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**Average: $1,365.70/yr**

### 125 HP

<table>
<thead>
<tr>
<th>Eff (w/o MPA)</th>
<th>(MPC) in $/yr</th>
<th>Eff (w/ MPA)</th>
<th>(MPC) in $/yr</th>
<th>Δ in $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.910</td>
<td>12,296.70</td>
<td>0.910</td>
<td>12,296.70</td>
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<tr>
<td>3/4L</td>
<td>0.850</td>
<td>13,164.71</td>
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<td>12,715.91</td>
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<tr>
<td>1/2L</td>
<td>0.700</td>
<td>15,985.71</td>
<td>0.750</td>
<td>14,920.00</td>
</tr>
<tr>
<td>1/4L</td>
<td>0.600</td>
<td>18,650.00</td>
<td>0.680</td>
<td>16,955.88</td>
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<tr>
<td>NL</td>
<td>0.400</td>
<td>27,975.00</td>
<td>0.520</td>
<td>21,519.23</td>
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</table>

**Average: $2,032.88/yr**
## Energy Savings

### 1 HP

<table>
<thead>
<tr>
<th>EFF (W/O MRC)</th>
<th>119.3% EFF in $/Yr</th>
<th>EFF (W MRC)</th>
<th>119.3% EFF in $/Yr</th>
<th>Δ in $/Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.650</td>
<td>183.63</td>
<td>0.700</td>
<td>170.51</td>
</tr>
<tr>
<td>3/4L</td>
<td>0.550</td>
<td>217.02</td>
<td>0.650</td>
<td>183.63</td>
</tr>
<tr>
<td>1/2L</td>
<td>0.400</td>
<td>298.40</td>
<td>0.550</td>
<td>217.02</td>
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<tr>
<td>1/4L</td>
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<td>397.87</td>
<td>0.500</td>
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<td>0.150</td>
<td>796.73</td>
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</table>

Avg: $156.87/Yr

### 5 HP

<table>
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<tr>
<th>EFF (W/O MRC)</th>
<th>596.80% EFF in $/Yr</th>
<th>EFF (W MRC)</th>
<th>596.80% EFF in $/Yr</th>
<th>Δ in $/Yr</th>
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</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.770</td>
<td>775.06</td>
<td>0.820</td>
<td>727.80</td>
</tr>
<tr>
<td>3/4L</td>
<td>0.650</td>
<td>916.15</td>
<td>0.750</td>
<td>795.73</td>
</tr>
<tr>
<td>1/2L</td>
<td>0.500</td>
<td>1193.60</td>
<td>0.650</td>
<td>918.15</td>
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<td>1492.00</td>
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<td>NL</td>
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<td>2984.00</td>
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Avg: $520.05

### 20 HP

<table>
<thead>
<tr>
<th>EFF (W/O MRC)</th>
<th>2387.20% EFF in $/Yr</th>
<th>EFF (W MRC)</th>
<th>2387.20% EFF in $/Yr</th>
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</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.825</td>
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<td>0.825</td>
<td>2693.58</td>
</tr>
<tr>
<td>3/4L</td>
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<td>3140.29</td>
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</tr>
<tr>
<td>1/2L</td>
<td>0.600</td>
<td>3978.67</td>
<td>0.680</td>
<td>5510.59</td>
</tr>
<tr>
<td>1/4L</td>
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<td>5304.89</td>
<td>0.570</td>
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<td>NL</td>
<td>0.300</td>
<td>7957.33</td>
<td>0.460</td>
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### Energy Savings

#### 50 HP

<table>
<thead>
<tr>
<th>EFF (W/0 MRC)</th>
<th>15,920.00 (EFF) in $/YR</th>
<th>EFF (W MRC)</th>
<th>15,920.00 (EFF) in $/YR</th>
<th>Δ in $/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.875</td>
<td>6,820.57</td>
<td>0.875</td>
<td>6,820.57</td>
<td>0</td>
</tr>
<tr>
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<td>7,460.00</td>
<td>0.850</td>
<td>7,021.18</td>
<td>438.82</td>
</tr>
<tr>
<td>0.650</td>
<td>9,181.00</td>
<td>0.730</td>
<td>8,175.34</td>
<td>1,006.20</td>
</tr>
<tr>
<td>0.500</td>
<td>11,936.00</td>
<td>0.620</td>
<td>9,625.81</td>
<td>2,310.19</td>
</tr>
<tr>
<td>0.350</td>
<td>17,057.45</td>
<td>0.570</td>
<td>11,901.96</td>
<td>5,149.47</td>
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</table>

**Ave.:** 1,820.94 $/YR

#### 125 HP

<table>
<thead>
<tr>
<th>EFF (W/0 MRC)</th>
<th>14,920.00 (EFF) in $/YR</th>
<th>EFF (W MRC)</th>
<th>14,920.00 (EFF) in $/YR</th>
<th>Δ in $/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.910</td>
<td>16,395.60</td>
<td>0.910</td>
<td>16,395.60</td>
<td>0</td>
</tr>
<tr>
<td>0.850</td>
<td>17,552.94</td>
<td>0.880</td>
<td>16,954.55</td>
<td>598.39</td>
</tr>
<tr>
<td>0.700</td>
<td>21,314.29</td>
<td>0.750</td>
<td>19,893.33</td>
<td>1,420.96</td>
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<tr>
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<td>28,692.31</td>
<td>8,607.69</td>
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**Ave.:** 2,710.51 $/YR

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**IVECO INC.**

**IMPROVEMENT VIA ELECTRONICS**
# ENERGY SAVINGS

## 3000 HOURS/YR

<table>
<thead>
<tr>
<th>HP</th>
<th>EFF (w/0 MAC)</th>
<th>(895.20) in %</th>
<th>EFF (w/0 MAC)</th>
<th>(895.20) in %</th>
<th>Δ in $/YR</th>
</tr>
</thead>
<tbody>
<tr>
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<td>275.45</td>
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<tr>
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<td>746.00</td>
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**Average:** $255.31/YR

## 5 HP

<table>
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<tr>
<th>EFF (w/0 MAC)</th>
<th>(895.20) in %</th>
<th>EFF (w/0 MAC)</th>
<th>(895.20) in %</th>
<th>Δ in $/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.770</td>
<td>1,162.60</td>
<td>0.820</td>
<td>1,091.27</td>
<td>70.89</td>
</tr>
<tr>
<td>0.650</td>
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<td>183.63</td>
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<td>1,790.40</td>
<td>0.650</td>
<td>1,377.23</td>
<td>473.17</td>
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<td>2,238.00</td>
<td>0.600</td>
<td>1,492.00</td>
<td>746.00</td>
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<td>4,476.00</td>
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<td>1,989.33</td>
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**Average:** $780.07/YR

## 20 HP

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<th>EFF (w/0 MAC)</th>
<th>(850.60) in %</th>
<th>EFF (w/0 MAC)</th>
<th>(850.60) in %</th>
<th>Δ in $/YR</th>
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<tbody>
<tr>
<td>0.825</td>
<td>4,340.36</td>
<td>0.825</td>
<td>4,340.36</td>
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<tr>
<td>0.700</td>
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<tr>
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<td>7,957.33</td>
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<tr>
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<td>11,936.00</td>
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<td>7,784.85</td>
<td>4,151.15</td>
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**Average:** $1,374.00/YR

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IVECO INC.

IMPROVEMENT VIA ELECTRONICS
### ENERGY SAVINGS

#### 50 HP

<table>
<thead>
<tr>
<th>EFF (W/ MRC)</th>
<th>$23,800.00/EFF</th>
<th>EFF (W/ MRC)</th>
<th>$23,800.00/EFF</th>
<th>Δ in $/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.875</td>
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<td>0.875</td>
<td>10,230.86</td>
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</tr>
<tr>
<td>0.800</td>
<td>11,190.00</td>
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<td>658.24</td>
</tr>
<tr>
<td>0.650</td>
<td>13,772.31</td>
<td>0.730</td>
<td>12,263.01</td>
<td>1,509.30</td>
</tr>
<tr>
<td>0.500</td>
<td>17,904.00</td>
<td>0.620</td>
<td>14,438.71</td>
<td>3,465.29</td>
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<tr>
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<td>25,571.14</td>
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<td>17,552.91</td>
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**Avg:** $2,731.41

#### 125 HP

<table>
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<th>$23,800.00/EFF</th>
<th>EFF (W/ MRC)</th>
<th>$23,800.00/EFF</th>
<th>Δ in $/YR</th>
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<td>0.910</td>
<td>24,593.41</td>
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<tr>
<td>0.700</td>
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<td>55,950.00</td>
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<td>47,038.76</td>
<td>12,911.54</td>
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**Avg:** $4,065.76/YR

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IVECO INC.

IMPROVEMENT VIA ELECTRONICS
APPENDIX M

COST/PRICE BREAKDOWN
**INCLUDES:** Ruggedized Industrial Grade (NEMA 1) Motor Power Controller

**CUSTOMER:** NASA/MSFC

**MODEL NO:** EYTU21A-A/A
**ITEM NO:** 1
**DATE:** 3-30-81

**1. MATERIAL:**

<table>
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<th>Material</th>
<th>Spoilage</th>
<th>Subcontract</th>
<th>Subtotal</th>
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<td>8%</td>
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**2. DIRECT LABOR:**

<table>
<thead>
<tr>
<th>Role</th>
<th>Est. Hours</th>
<th>Rate Per Hour</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program Manager</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Planner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Writing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and Drafting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Technician</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabrication-Prototype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assembly-Prototype</td>
<td></td>
<td></td>
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<tr>
<td><strong>TOTAL ENGINEERING LABOR</strong></td>
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**BURDEN @ 120%**

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<tbody>
<tr>
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<tr>
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<tr>
<td>Winding</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Q.C. Engineering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection</td>
<td>0.20</td>
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<td><strong>TOTAL MANUFACTURING LABOR</strong></td>
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**BURDEN @ 120%**

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<th>Estimated Cost</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$ 14.29</td>
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**3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing)** $ 22.90

**4. TOTAL DIRECT COSTS PLUS BURDEN** (Line 1 plus Line 3).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39.55</td>
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</tbody>
</table>

**5. G & A** 13.5% of Line 4

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.34</td>
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</table>

**6. SUBTOTAL**

<table>
<thead>
<tr>
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**7. PROFIT** 15% of Line 6

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</thead>
<tbody>
<tr>
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**8. TOTAL ESTIMATED PRICE**

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>$ 51.62</td>
</tr>
</tbody>
</table>
**Includes:**
Ruggedized Industrial Grade (NEMA 1)
Motor Power Controller
Single-Phase, 5 HP, 240VAC, 60Hz

**Customer:** NASA/MSFC

**Quotation No:** ---
**Model No:** EY1021A-D/B
**Item No:** 2
**Date:** 3-30-81

### 1. Material:
- Material: $17.25
- Spoilage 3%: $0.52
- Subcontract: $17.77
- Subtotal: $1.42

**Material Handling:** 8% ($19.19)

### 2. Direct Labor:

<table>
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<tr>
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<th>Hours</th>
<th>Rate Per Hour</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program Manager</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Planner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Writing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and Drafting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Technician</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabrication-Prototype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assembly-Prototype</td>
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<td></td>
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<td><strong>Total Engineering Labor</strong></td>
<td></td>
<td></td>
<td><strong>$</strong></td>
</tr>
<tr>
<td><strong>Burden @ %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Technician</td>
<td>0.15</td>
<td>$7.50</td>
<td>$1.13</td>
</tr>
<tr>
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<td>2.15</td>
<td>$4.10</td>
<td>$8.82</td>
</tr>
<tr>
<td>Fabrication</td>
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<td>Winding</td>
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</tr>
<tr>
<td>Q.C. Technician</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q.C. Engineering</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Analysis</td>
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<td><strong>Total Manufacturing Labor</strong></td>
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<td><strong>$11.70</strong></td>
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<tr>
<td><strong>Burden @ 120 %</strong></td>
<td></td>
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<td><strong>$14.04</strong></td>
</tr>
</tbody>
</table>

### 3. Total Direct Labor Including Burden (Engineering & Manufacturing) **$25.74**

### 4. Total Direct Costs Plus Burden (Line 1 plus Line 3) **$44.93**

### 5. G & A 13.5% of Line 4 **$6.07**

### 6. Subtotal **$51.00**

### 7. Profit 15% of Line 6 **$7.65**

### 8. Total Estimated Price **$58.65**
**INVOICE**

**INQUIRES:**
- Ruggedized Industrial Grade (NEMA 1)
- Motor Power Controller
- Three-Phase, 10 HP, 240VAC, 60 Hz

**CUSTOMER:** NASA/MSFC

**QUOTE NO:**

**MODEL NO:** EY1027A-E/R

**ITEM NO:** 3

**DATE:** 3-30-81

---

### 1. MATERIAL:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>Spoilage</td>
<td>3 %</td>
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<tr>
<td>Subcontract</td>
<td>----</td>
</tr>
<tr>
<td>Subtotal</td>
<td>----</td>
</tr>
<tr>
<td>Material Handling</td>
<td>8 %</td>
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</table>

**TOTAL MATERIAL** ........................................... $ 74.53

---

### 2. DIRECT LABOR:

- **Program Manager**
- **Engineering Planner**
- **Electronic Engineer**
- **Reliability Engineer**
- **Mechanical Engineer**
- **Technical Writing**
- **Design and Drafting**
- **Engineering Technician**
- **Fabrication-Prototype**
- **Assembly-Prototype**

**TOTAL ENGINEERING LABOR** ....................... $ 1.35

**BURDEN @ 140 %** ........................................ 1.89

- **Production Technician**
- **Production Assembly**
- **Fabrication**
- **Winding**
- **Q.C. Technician**
- **Q.C. Engineering**
- **Analysis**
- **Inspection**

**TOTAL MANUFACTURING LABOR** ..................... $ 24.93

**BURDEN @ 120 %** ........................................ 29.92

---

### 3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing) $ 58.09

### 4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3) ........... 132.62

### 5. G & A 13.5 % of Line 4 .......................... 17.90

### 6. SUBTOTAL ................................................. 150.52

### 7. PROFIT 15 % of Line 6 .................. 22.58

### 8. TOTAL ESTIMATED PRICE ......................... $ 173.10
### IVECO

**INCLUDES:**
- Ruggedized Industrial Grade (NEMA1)
- Motor Power Controller
- Three-Phase, 10 HP, 480VAC, 60 Hz

**CUSTOMER:** NASA/MSFC

**QUOTE NO:** ---

**MODEL NO:** EY1027A-E/C

**ITEM NO:** 4

**DATE:** 3-30-81

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**1. MATERIAL:**

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<td>Spoilage 3%</td>
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<tr>
<td>Subtotal</td>
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<td>Material Handling 8%</td>
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**TOTAL MATERIAL:** $74.53

---

**2. DIRECT LABOR:**

<table>
<thead>
<tr>
<th>Position</th>
<th>Est. Hours</th>
<th>Rate Per Hour</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program Manager</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Planner</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electronic Engineer</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Reliability Engineer</td>
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<td></td>
</tr>
<tr>
<td>Mechanical Engineer</td>
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<td></td>
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<tr>
<td>Technical Writing</td>
<td></td>
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</tr>
<tr>
<td>Design and Drafting</td>
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<td></td>
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<td>0.20</td>
<td>$9.00</td>
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<tr>
<td>Assembly-Prototype</td>
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**TOTAL ENGINEERING LABOR:** $1.80

**BURDEN @ 140%**

<table>
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<th>Position</th>
<th>Est. Hours</th>
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</tr>
</thead>
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<tr>
<td>Production Technician</td>
<td>0.60</td>
<td>7.50</td>
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<td>4.25</td>
<td>2.13</td>
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<tr>
<td>Winding</td>
<td></td>
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</tr>
<tr>
<td>Q.C. Technician</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Q.C. Engineering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
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<tr>
<td>Inspection</td>
<td>0.60</td>
<td>4.10</td>
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**TOTAL MANUFACTURING LABOR:** $26.93

**BURDEN @ 120%**

<table>
<thead>
<tr>
<th>Position</th>
<th>Est. Hours</th>
<th>Rate Per Hour</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Technician</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Assembly</td>
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</tr>
<tr>
<td>Fabrication</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inspection</td>
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</tr>
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</table>

**3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing):** $63.57

**4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3):** $138.13

**5. G & A 13.5% of Line 4:** $18.65

**6. SUBTOTAL:** $156.78

**7. PROFIT 15% of Line 6:** $23.52

**8. TOTAL ESTIMATED PRICE:** $180.30
### Material Lists

#### 1ø, 120VAC, 60 Hz, 1 HP

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<tr>
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<th>Price</th>
<th>Quantity</th>
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<tr>
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<td>3.80</td>
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<td>Triac</td>
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**Total Material**: $14.97/unit

#### 1ø, 240VAC, 60 Hz, 5 HP

<table>
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<tr>
<td>PCB</td>
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<td>$2.50</td>
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<tr>
<td>Enclosure</td>
<td>3.80</td>
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<tr>
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<tr>
<td>Electronics</td>
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<td>4.50</td>
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<tr>
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**Total Material**: $17.25/unit

#### 3ø, 480VAC, 60 Hz, 10 HP

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<tr>
<td>Enclosure</td>
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<td>4.60</td>
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<tr>
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<td>Power Magnetics</td>
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<td>Hardware/Misc.</td>
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**Total Material**: $70.00/unit

---

**IVECO INC.**

**Improvement via Electronics**