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**SCHOLARLY RESEARCH
PROGRAM**

**Delivery Order 0011: Concept Design for a
1 MW Generator Based on a Permanent
Magnet Rotor (Turbine Driven)**

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14. ABSTRACT The final report documents a conceptual design for a generator capable of generating 1 MW electrical output at 200 VDC with a shaft speed of 15,000 rpm and a maximum outer diameter of 15 inches. It is based on an interior permanent magnet rotor configuration with three phase output. The designs were developed and analyzed using the PC-BDC software which is part of the SPEED (Scottish Power Electronics and Electric Drives consortium) motor/generator analysis suite. Results indicate that the 1 MW generator would have an active magnetic weight of 158-300 lbms which would translate into a total machine weight of approximately 250 - 450 lbms. Thermal management of the designs was not analyzed in detail due to the limited scope of the project. This effort was performed under a delivery order contract to Motorsoft; Universal Energy Systems was the contractor.						
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1.0 Introduction

The most significant difference between aerospace turbine driven generators or alternators as compared to conventional generators is high power density for the lowest possible weight. No matter which magnetic configuration is selected expensive high performance materials and perhaps even higher manufacturing cost within reason are minor considerations. Even a small savings in generator size as a result of using the best designs and materials can yield rapid paybacks by substantial fuel savings. In the case of certain unmanned airborne vehicles that use generators the lower generator weight yields increased payloads. The design of conventional generators is not based on these principles.

For these high power density machines there seems to be two categories of generators, KW machines and MW machines. For all types there are some historically common magnetic configurations.

- A - Axial field (wound or PM)
- B - Conventional wound radial field
- C – Conventional surface PM rotor (developed by Gene Aha)
- D - PM flux squeezing radial field (developed by Dr E. Richter & Dr. L.J. Bailey)
- E - Claw-rotor with wound or OM field (common with automotive)
- F - Homopolar

There has been much debate and design comparisons performed over the last 30 or more years as to which magnetic circuit configurations are the best choices for each application. A brief summary from the debaters to form some general conclusions is provided so we can get on with this conceptual design of a 1 MW generator.

The claw rotor type can be disregarded at once because several studies have shown that its output is 1.5 to 5 time worse than the best radial field configurations. These same studies show that the flux squeezing radial designs are the best for the smaller generators in the KW & up category. For the MW generator category the studies show that the conventional surface mounted magnet rotor types offer the highest power densities. These are difficult to control as compared to wound field machines with PM exciters but not impossible.

There is a newer type of PM machine that bears careful study that is known as an interior magnet machine that has its output power produced by two magnetic fields linking the stator phase windings. With the magnets of the surface mounted rotor placed just below the surface of the soft iron steel rotor core with soft iron completely over the magnet at the airgap part there exists a reluctance component of the output power. This can be thought of as a hybrid SR/PM synchronous generator. The permanent magnet pole arc and the soft iron poles between the magnets are critical in the design to achieve the balance between the Reluctance and the PM components of flux linkage. The output seems to be easily controlled by the adjustment of the angle between E (back emf) & V (output volts). This same sort of output control can be implemented with

surface mounted magnets but not as effectively as with interior magnets. The flux linkage is much easier to change because the soft iron poles are isotropic and the flux can easily be moved tangentially in the poles to control flux linkage. This type of machine is currently being used by Toyota for the Prius hybrid automobile. The output power falls into the KW category. Perhaps some version of this interior magnet machine is worth considering for the MW size machines. (It is important to note that rpm and output power levels both are important considerations and usually drive the final design choices for the magnetic circuit selection.)

It is understood that WPAFB has issued contracts for more or less conventional 1 & 2 MW generators with wound field radial magnetic circuits. Therefore we have tried to optimize a surface mounted PM type, 1 MW generator using some of the processes developed by both Fisher and Motorsoft for the rotor and the stator construction. The goal was for the highest power density possible so the machine is of course assumed to be liquid cooled. The rotor is designed for a high number of poles to reduce the magnetic iron volume and weight required. The cross section of the stator yoke iron is cut in half each time the number of poles is doubled. The weight of heavy magnetic materials comes down rapidly with increasing number of poles. High pole machines are now technically feasible due to the advances in power semiconductors, high speed micro-processors such as DSP's (digital signal processors) and low core loss lamination materials.

The stator design is based upon a lamination construction developed and patented by Fisher that allows the use of the best lamination materials to minimize the core losses and also eliminates wasted material from the stamping process. The stator would be epoxy encapsulated with the latest thermal conductive materials to improve the conduction of the heat sources to the cooling medium through a liquid cooling jacket.

2.0 Summary of Generator Requirements

2.1 Specified Design Goals

1. One megawatt output continuous @ rated speed
2. Three phase output or two three phase circuits
2. 200 VDC after FWBR (full wave bridge rectifier), fully loaded, thermally stable at operating temperature. (200 VDC =141.4 Vrms L-L)
3. Rated speed = 15,000 RPM
4. Liquid cooled (250 F incoming)
5. Maximum O.D. = 15 inches over frame

2.2 Assumptions Used for Design Concept

1. Radial air gap machine
2. Surface-magnet rare-earth PM alternator with external power conditioner. (2-17 Samarium Cobalt selected due to high temp. stability)
3. Aluminum frame / cooling jacket about 0.75 inches thick per side. (13.50" stator diameter.)
4. Best materials to be selected including insulation system

3.0 Summary of Initial Sizing of Design Concept

3.1. Rotor Diameter Selection

The larger the rotor diameter, the more torque that can be developed per axial length of active magnet, by approximately D^2 . So the question is: *“What is the largest diameter rotor that can run at 15000 rpm?”*

The diameter is limited by the ability to retain the magnets. The ability to retain the magnets is limited by the strength and pre-stress of the material used for the retainment band.

A suitable nonmagnetic super alloy is chosen for this design which, when analyzed with our retainment ring program, dictates the following design based on allowed stress:

2 X 0.020” thick bands over 8.0 inch diameter magnets (0.040” thick)
Lift-off speed 16442 (must be greater than 15000 rpm)
Safety factor 1.25
Effective band stress, installed 206,000 psi
Interference at installation: 0.080 in. (required for initial pre-stress)

With a retainment band of **0.040”thick** and an additional mechanical gap of 0.020” per side the magnetic design is based upon a magnetic air gap of **0.060”** over an 8.00” diameter rotor.

3.2. Rotor Length Selection

The following is a summary chart of the airgap shear stress (Torque/rotor radius/ rotor swept area at airgap) used by the standard surface magnet machines produced by Fisher for the past 10 years for forced air-cooled machines. (Increases with diameter)

Model Number	Rotor Diam.	Torque per Axial length (100 C rise)	Gap Shear Stress PSI
M2.5	2.5 in	2 lb-ft	2.44
M3	3.0 in	3 lb-ft	2.55
M5	5.0 in	9 lb-ft	2.75
M7	7.0 in.	21 lb-ft	3.27
M10	10.0 in	52 lb-ft	3.97

From above we selected a rotor O.D. of 8.00”, a starting shear stress is interpolated from the above data needed to select the rotor and stator length. (8” rotor results in a projected shear stress of 3.5 psi which is reasonable for 250 deg F liquid cooling as about equal to the highly forced air cooled machines from Fisher).

Projected torque per axial inch is 29.3 Lb-ft

Required torque is 469.5 Lb-ft (1000 KW at 15000 RPM)

Required active rotor length is 16.0 inches

3.3 Allowable losses

All machines exhibit a certain surface area for the heat to conduct into the liquid cooling jacket or to a finned air cooled jacket. The following chart summarizes some important data taken from the existing machines designed, built and tested by Fisher such as the stator surface loss density. We assume the coil to frame thermal resistance to be 50% of the total thermal resistance of the machine. (deg C/ kW)

Mode	Gap Diam	Stator OD	Stator sq-in/in	Rtheta C/kW Coil-frame	Est W/inAxial	Watts Per in^2
M5	5.0"	6.5	20.4	35	224	10.9
M7	7.0 "	8.45	26.5	26	387	14.6
M10	10.0"	12.16	38.2	9	428	11.2

Average loss density at surface of stator lamination OD is 12.2 W/in^2

Calculate allowable coil temperature:

Required life: 200 hrs at full load.

Assume short life of materials is OK—180 C materials at 180 C = 20 years = 175kHrs

Life is shortened by running above continuous life temps:

Temp	Life
180	175.2k
190	87.6k
200	43.8k
210	21.9k
220	10.9k
230	5.5k
240	2.7k

Therefore, design for 240 C operation with 180 C materials.

Therefore, allowable temp rise of stator cooled with 250F (121C) coolant is 120C

Based on Fisher experience:

Using 12W/in^2 for 60 C rise

24 W/in^2 for 120 C rise of same machine is projected

For an 8-pole machine, with about 3X slot area and 3X back iron compared to Fisher 24-pole designs, but with thermal encapsulation, project 0.75 effectiveness or 18W/in^2 .

Allowing for 1.5 inches radially for coolant jacket, from 15 in. allowable OD, leaves 13.5 in. OD at stator lams.

OD swept area for the air gap is $13.5 \times 3.1414 \times 16 = 678.6$ in sq.

Allowable loss would then be 12,204 Watts which implies 98.8% efficiency goal

3.4: Projected Stator Phase Resistance

Begin with a 50/50 losses between total Copper and Iron.

Therefore allowable copper losses would be 6102 Watts.

Assume 3-phase machine

Therefore loss per phase would be 2034 Watts

For coil temp of 240 C, the increase in resistance above 25 C ambient is 1.83

Therefore, the equivalent loss at 25 C would be 1112 Watts/phase

Calculate phase current:

DC Current: For 1000 MW at 200 Vdc requires 5000 Adc.

Assuming, for FWBR, $I_{ac}/I_{dc} = 0.78$,

AC Current: $I_{ac} = 3900$ Amps/phase

Assume 8 parallel circuits for winding, the per circuit current is 488 Amps (ac), and per circuit copper loss would be 139 Watts.

Conclusion: required resistance, per parallel circuit is 0.58 mOhms (25C)

3.5 Required Turns per Coil

First voltage drop assumption is 25% drop due to series impedance full load

Then required BEMF at 240C is 265 0-peak, L-L, per pole, or 17.7 Vpk, L-L/krpm.

Then required BEMF at 240C is 153 0-peak, L-N, per pole (fundamental).

Calculate pole area: for 16 inch stack, 8 pole,

$A_{pole} = 50.3 \text{ in}^2 = 0.0324 \text{ m}^2$

Assume: $B_{pk\ gap} = 0.75T$ at 240 C (= 0.80T at 20 C)

Then E_{pk} , L-N, per turn is: 153.0 Volts

This can be achieved by winding each coil with 1 turn with a 16 inch long stack (for 8 poles)

3.6 Flux per pole calculation

$R_{gap} = 4.0$ inches

$L_{gap} = 16$ inches

$B_{gap} = 0.75$ T

Poles = 8

$\Phi_{gap/pole} = 24.3$ mWb

3.7 Slot area

Length of coils:

Assume: Mean Length of end turns is at 1.5 inches larger than ID of 8 inches. At this radius, the pole pitch is 3.73 inches. Allow 0.5 inches for coil exit at the stack and take the end turn length to be:

$L_{et} = 0.5 + 3.73 + 0.5 = 4.73$ inches

Then $\frac{1}{2}$ the coils will have total length of:

$2 \times \text{Stack} + 2 \times L_{et} = 41.5$ inches

and $\frac{1}{2}$ will be:

$2 \times \text{Stack} + 1 \times L_{et} = 36.7$ inches

Average length per turn is 39.1 inches.

To get 0.58 mOhms at 25 C, need A_{cu} of 0.043 in^2 , or diam = 0.2338 inch (54,662 cm = 54 strands of #20 AWG)

With two coil sides per slot, Cu area will be 0.086 in^2 .

With heavy film, Wire area will be 0.104 in^2

With 0.45 mechanical fill factor, coil Slot area needs to be 0.231 in^2

Also, slot pitch at stator ID, for 3 slots per pole, is 1.047 inches, which means if slot and tooth are the same area, each is about 0.523" wide at the stator ID.

Slot area needs to be at least 0.231 sq inches min.

3.8 Stator Core Volume

Assume (from above) allowable core loss is 6102 Watts

Loss can be approximated by
 $P_{fe} = k_{fe} \cdot f^m \cdot B^n \cdot \text{Volume}$

B in teeth is different than B in back iron, so total loss is:
 $P_{tot} = P_{fe_teeth} + P_{fe_backiron}$

Frequency is the same, so B and volume of teeth and back iron are 4 variables we can use to apportion losses. Also the material itself is an available choice. The following analysis can be done parametrically, but it's faster to just calculate by trial and error.

Assume tooth/slot area percentage ratio is between 25/75 – 75/25. For Slot area of 0.231 in², calculate tooth areas (axial section), with the slot pitch constrained to 0.523 inches at the stator ID.

The required slot depth, d_s , to achieve the necessary slot area for N_{sp} slots per P poles is the solution of the following quadratic equation:

$$d_s^2 + (2 R_{id}) d_s - (N_{sp} P A_s) / (\pi K_s) = 0$$

where: d_s = slot depth

R_{id} = stator inner radius

N_{sp} = Number of slots per pole

P = number of poles

A_s = required slot area

K_s = Fraction that slot area is of total slot pitch area ($=A_s + A_t$)

Tooth/Slot Ratio	dslot	Width Slot top	Width Tooth top	Width Slot bottom	Width Tooth bottom
25/75	0.284	0.785	0.262	0.841	0.280
33/67	0.317	0.702	0.346	0.757	0.373
40/60	0.352	0.628	0.419	0.684	0.456
45/55	0.383	0.576	0.471	0.631	0.516
50/50	0.419	0.524	0.524	0.578	0.578
55/45	0.463	0.471	0.576	0.526	0.643
60/40	0.518	0.419	0.628	0.473	0.710
67/33	0.620	0.346	0.702	0.399	0.810
75/25	0.802	0.262	0.785	0.314	0.943

Note: Teeth could be tapered for trapezoidal teeth and slots. (All examples modeled in PC-BDC teeth are based on parallel-sided teeth)

Considering there are about 2.75 inches radially available for teeth plus back-iron, it looks like there is room for larger (deeper) slots, more iron and lower overall losses. The other alternative is to reduce the stator O.D. which would reduce weight substantially.

Given the tooth width, the no-load flux density in the teeth can be estimated. The flux per pole is given by:

$\Phi_{\text{pole}} = 24.3 \text{ mWb}$, and flux per tooth is 8.10 mWb

Tooth volume summary:

Tooth/Slot	Tooth Top Width	Tooth gap Area in ²	Btooth	Vol Tooth in ³	Vol Teeth total
25/75	0.262	4.02	3.59	4.16	99.9
33/67	0.346	5.31	2.72	5.52	132.4
40/60	0.419	6.43	2.24	6.72	161.2
45/55	0.576	7.238	1.99	7.585	182.0
50/50	0.524	8.042	1.80	8.464	203.1
55/45	0.471	8.847	1.63	9.359	224.6
60/40	0.628	9.65	1.50	10.28	246.6
67/33	0.702	10.78	1.34	11.61	278.7
75/25	0.785	12.06	1.20	13.27	318.6

Back Iron volume calculations:

Assume: Flux density in back iron is the same as in teeth, although it can be independently controlled

Note: Max OR_{bi} is about 6.75 inches

Bback iron	Abi (m2)	Abi (in ²)	d _{bi} (in)	IR _{bi} (in)	OR _{bi} (in)	Vol _{bi} (in ³)
3.59	1.02E-02	15.7	1.02	4.28	5.31	474.2
2.72	1.34E-02	20.8	1.35	4.32	5.67	651.6
2.24	1.62E-02	25.2	1.64	4.35	5.99	818.1
1.99	1.83E-02	28.3	1.84	4.3828	6.23	944.0
1.80	2.03E-02	31.5	2.05	4.4192	6.47	1076.4
1.63	2.23E-02	34.6	2.25	4.4634	6.72	1215.9
1.50	2.44E-02	37.8	2.46	4.52	6.98	1363.7
1.34	2.72E-02	42.2	2.75	4.62	7.37	1588.0
1.20	3.05E-02	47.2	3.07	4.80	7.88	1880.1

3.9 Core Losses calculations:

Material choices:

Inputs: $f = 1000 \text{ Hz}$

$B_{\text{teeth}} = 1.63$

$B_{\text{backiron}} = 1.63$ (same as B_{th})

$$P1 = K * f^m * B^n \text{ W/kg}$$

$$P2 = K_h * f^1 * B^{a+b} + K_e * f^2 * B^2 \quad (\text{Steinmetz})$$

Material	K (W/kg)		m for f exp (a)	n for B exp	Material density kg/cm ³
Cogent M3 0.009" thk	0.0007563		1.693	2.060	0.00765
	Kh	Ke	a, b for Bh	for Be	
Hiperco 50 6 mil	0.023149	7.2753e-7	1.7, 0	2.00	0.00811
Arnon7 M15) 7mil	0.020589	2.3986e-6	2.977, 0	2.00	0.00745
Metglas				2.00	
M19 29Ga (14 mil)	0.0.01874	3.2187e-6	a=1.308, b=0.356 at = 2.105 abi=1.838	2.00	0.00745

	Loss Density In Teeth W/kg	Teeth Core Loss Watts	Loss Density In Backiron W/kg	Bklron Core Loss Watts	Total Core Loss Watts
Cogent M3 (9 mil) ***	248.84	5029	248.84	30550	35579
Hiperco 50 (6 mil)	55.17	1182	55.17	7180	8362
Arnon (7mil)	55.84	1200	55.84	7267	8463
M19 29Ga (14 mil) ***	94.89	1868	94.89	11345	13212

*** = doubtful calculation, don't have Steinmetz coefficients

Check against allowable losses: Allowable core loss is 6102 Watts. Hiperco is the highest density magnet material available and one of the lowest in core loss.

Selection of Hiperco 50, 6 mil thick:

Note: loss is higher than expected allowance of 6102 Watts. With the core being in direct contact with the cooling jacket, it is conceivable that this will be acceptable. A thorough thermal model is necessary to investigate this more closely. Also, it appears there may be room to use extra iron to lower flux densities and losses.

The selection of 55/45 ratio of tooth to slot seems to be a good starting point:

Dslot = 0.4634
Width_slottop = 0.471
Width_toothtop = 0.576 (not incl tooth tip)
Width_slotbottom = 0.526
Width_toothbottom = 0.643
IR backiron = 4.4634
OR of back iron = 6.72

Wgt Bi = 108.7 kg = 239 lbs
Wgt tth = 21.4 = 47.1 lbs
Wgt total = 130.15 kg = 286.8 lbs

3.10 Demagnetization

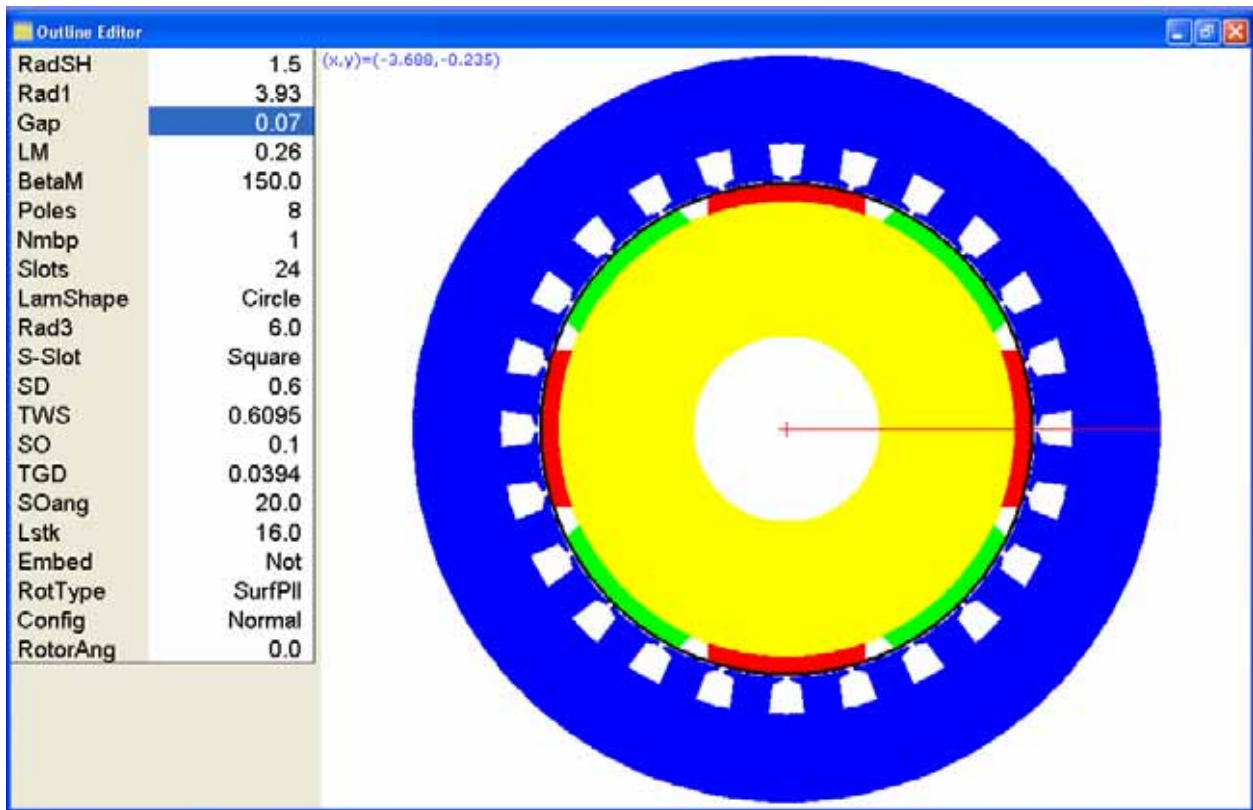
Inputs: Turns/pole: 1
Amps/pole: 488 rms, (apprx 690 peak)
Air-gap: 0.060 inches
Magnet thickness: 0.25 inches
Mag temp: 250C
H_arm(pk) = 175 kA/m (about 2.2 kOe) Taken from vender B-H curve
Approx PC = $0.25/0.06 = 4.2$ (PC-BDC shows 3.8)

Using Sm2Co17 (Arnold S3/245), there should be no problem with demagnetization at this current and temperature. PC-BDC model uses Shin-Etsu R33H Samarium.

4.0 Simulation Results Using PC-BDC (SPEED Software)

Using PC-BDC this design was refined and it was determined that the slots should be much deeper to reduce the copper losses at the expense of core iron losses.

4.1 Cross Section Per Sizing From Section 3.0



The final lamination O.D. was reduced from the projected of 13.50" to 12.00" diameter.

1.013 MW Output @ 15,000 rpm, 205 VDC rectified

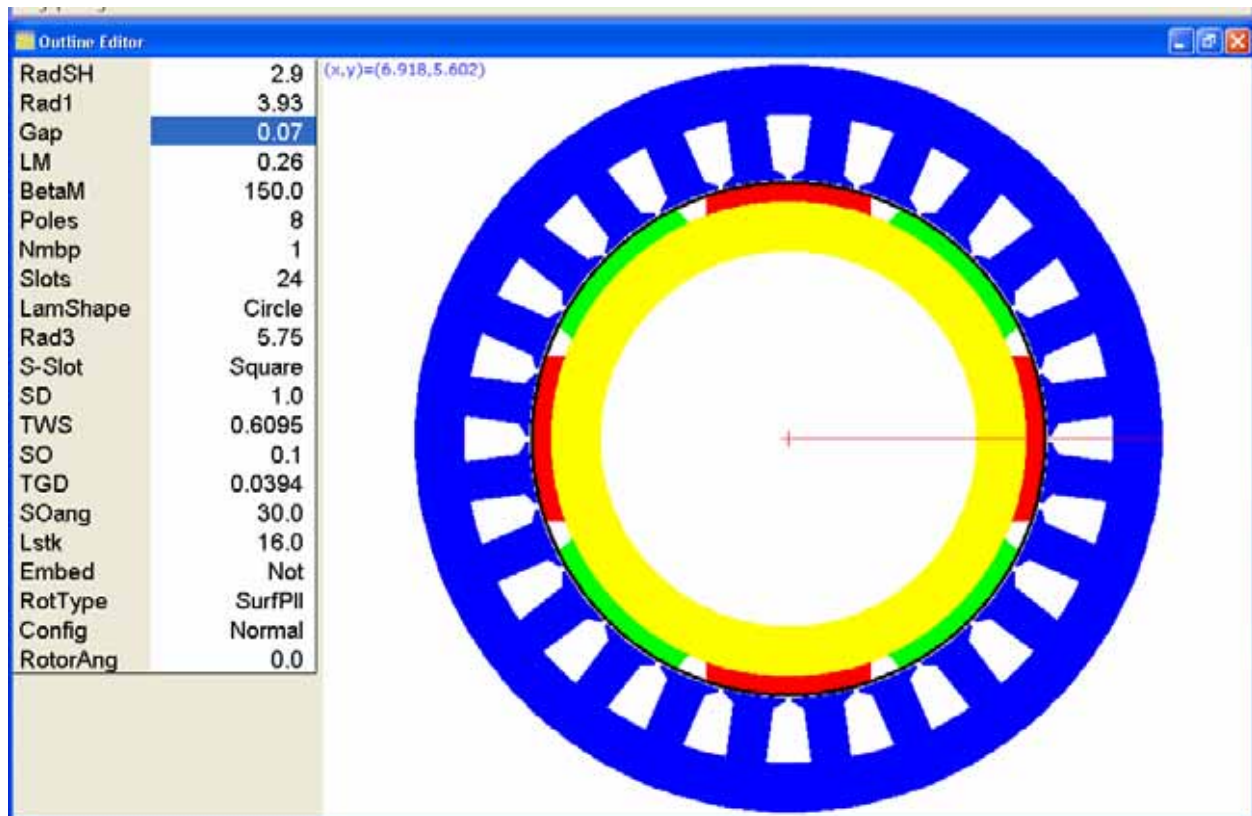
Total Losses = 10807 W, Efficiency = 98.95%

Copper Losses = 5416 W Iron Losses = 4885 W Rotor Losses = 505 W

The cross section shown is based on copper losses and iron losses that are close to equal based upon the original assumptions used to size the unit. Since the heating due to copper losses is much more difficult to remove via liquid cooling than iron losses, the copper can be reduced as the iron losses increases. This assumes the O.D. and stack of the machine are retained. After several iterations it was found that when the slot depth is increased to provide more winding space for larger wire cross section, the copper losses are reduced faster than the iron losses are increased. The cross section

of the back iron decreases as the slot depth is increased which increased the flux density and iron losses in the stator yoke. The next cross section shows the results of more winding space using deeper slots and less back iron or yoke thickness.

4.2 Revised Cross Section for Higher Iron Losses & Lower Copper Losses



The stator lamination O.D. was further reduced from 12.00 to 11.00" diameter.

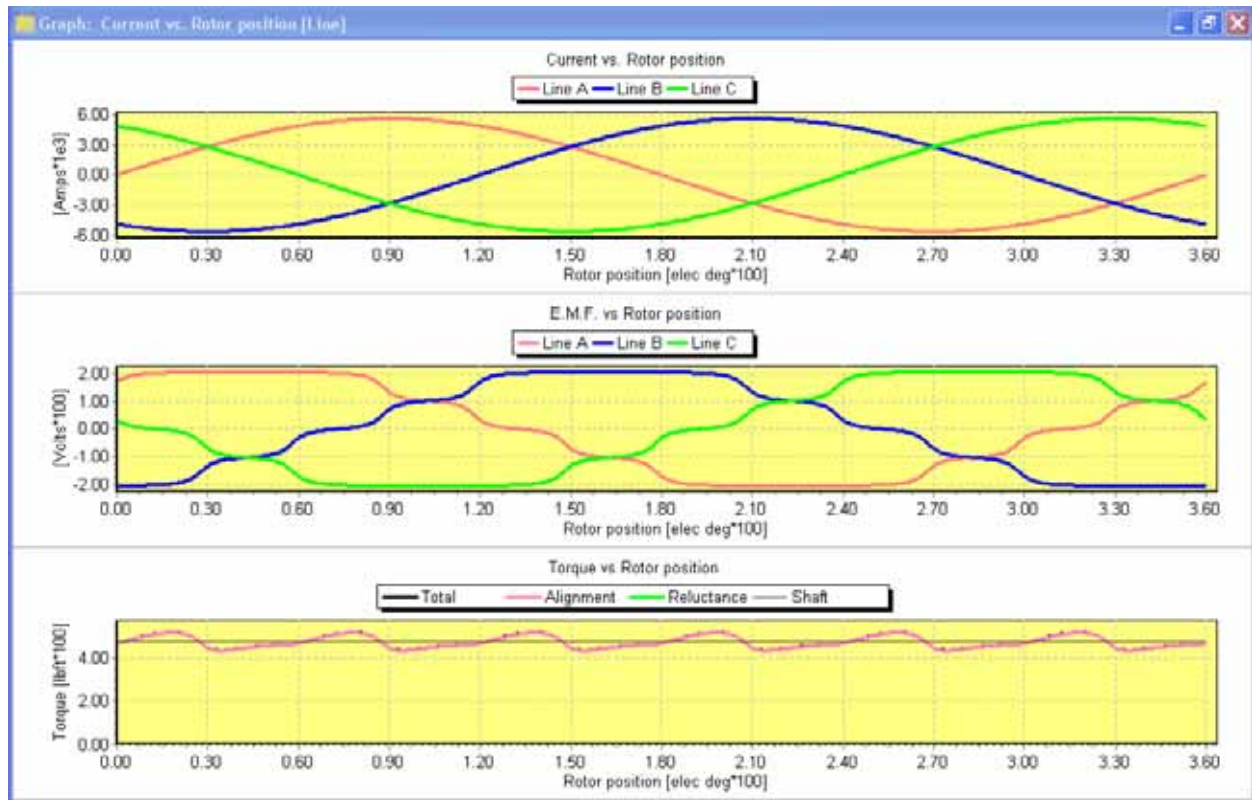
1.003 MW Output @ 15,000 rpm, 205 VDC rectified

Total Losses = 9635 W, Efficiency = 90.04%

Copper Losses = 2826 W Iron Losses = 6304 W Rotor Losses = 505 W

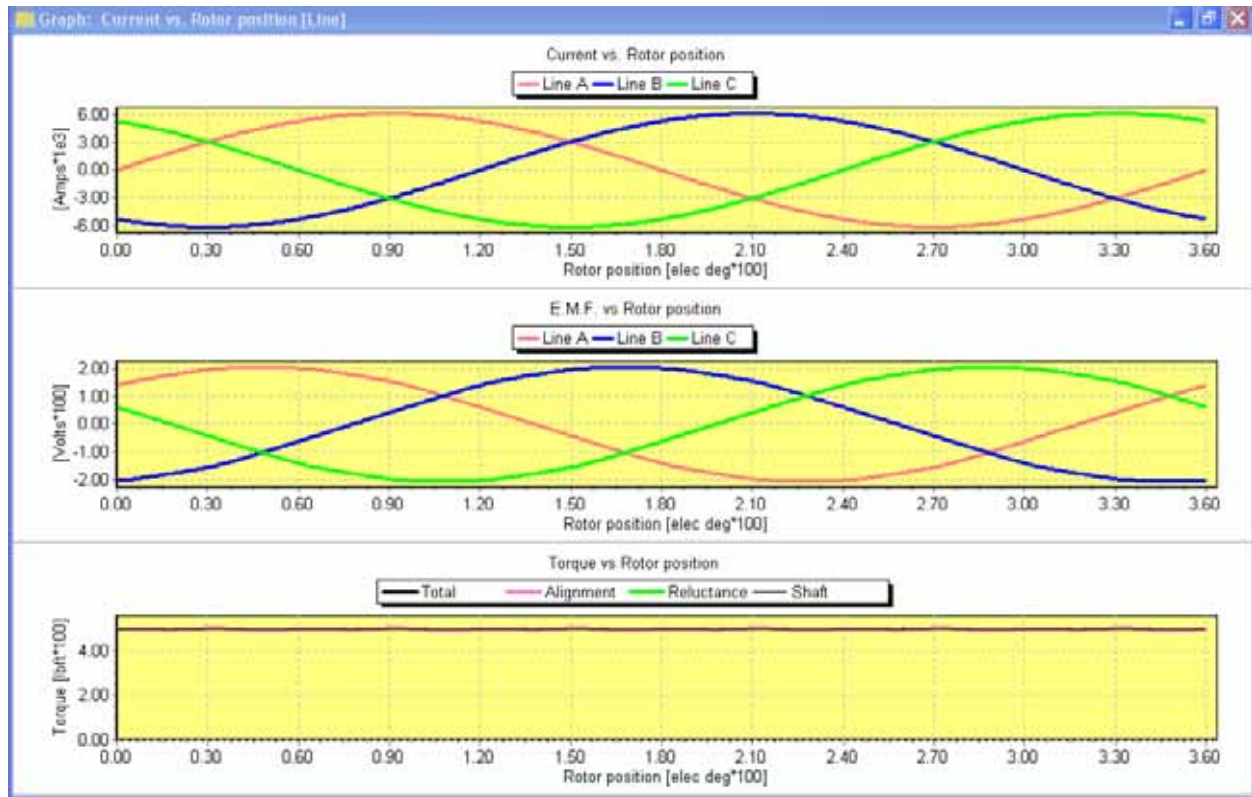
The efficiency has increased slightly and the copper losses are reduced substantially with a less correspondingly increase in iron losses. The extra heat generated from the iron losses is easily extracted due to the lamination contact with the cooling jacket.

4.2.1 Simulated Output Curves @ 15,000 RPM



A sinusoidal shaped voltage wave shape is most desirable from line to line. The middle graph above indicates that an improvement is required. However with the current slot to pole combination, the resulting flux linkage yields the optimum power density. The wave shape can be improved a number of ways but each will reduce the power density slightly. The next example shows those results using the exact same machine dimensions but with magnet overhang and a full stator slot skew to cause the back emf to be sinusoidal.

4.2.2 Simulation Results Using A One Slot Stator Skew



The skewing of either the stator or the rotor magnets equal to the angle between two adjacent stator slots ($360 \text{ deg}/24 \text{ slots} = 15 \text{ deg skew}$) results in a very nearly perfect sine wave back EMF which results in near zero torque ripple seen by the turbine during generating. The control angle between the output voltage and the back EMF must be increased slightly from 22.5 deg to 25 deg in order to achieve the 1 MW output. This results in a drop in efficiency and higher copper losses, which seems to be still OK. (The stator skewing also reduced the output voltage so some magnet overhang to the stator length was added to increase the flux to compensate for that lost by the skewing.)

1.016 MW Output @ 15,000 rpm, 200 VDC rectified

Total Losses = 10157 W, Efficiency = 99%

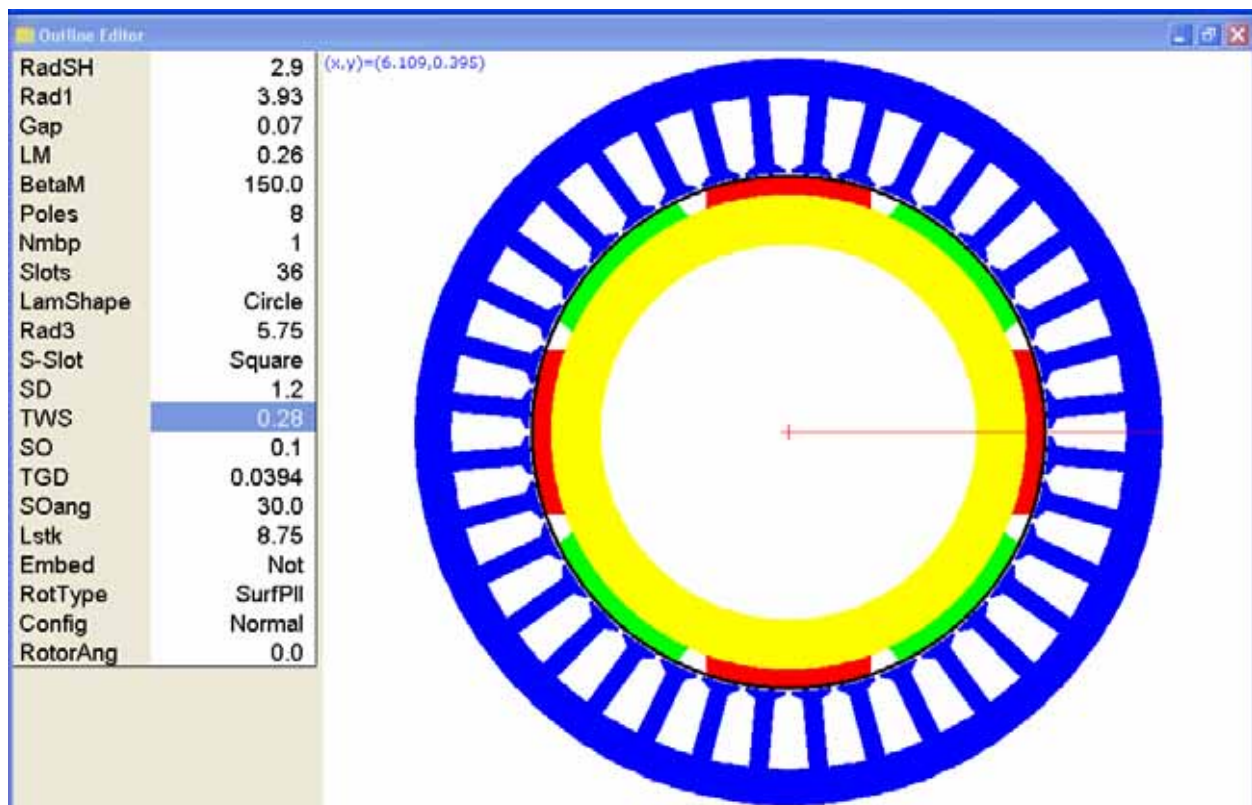
Copper Losses = 3063 W Iron Losses = 6565 W Rotor Losses = 530 W

4.3 High Power Density Generator design.

One more design consideration is presented for a very high density PM generator with the same 12.00" stator O.D. & 13.50" frame/cooling jacket O.D. The 8-pole rotor over the magnets is the same as the previous designs at 8.00" O.D. The main difference is the stack length is shortened from 16" to 8.75" The number of stator slots was increased in accordance with the new stack length to achieve the same output voltage at 15,000 rpm under full load of 1 MW. Since the coils cannot be wound with less than a single turn per coil the 8 parallel paths then had to be changed to 4 through the phase windings to achieve the correct number of effective turns to go with the reduced magnet flux required to generate the rectified 200 VDC min. Both the current density (amps/cross section of copper per turn) and the stator lamination flux density are higher than the other designs. Since the rotor is much shorter than the other designs the gap shear stress increased from 3.6/3.7 psi to 6.8 psi.

Neither Fisher nor Motorsoft have ever attempted such a high a power density machine but many other designs are as high as 10 psi. However this 6.8 value is certainly achievable as long as the cooling system can remove the heat from the windings and the laminations. A more detailed design simulation analysis would be required using a good thermal FEA package. From such an analysis the needed flow of cooling oil could be determined to facilitate cooling to prevent the windings from ever exceeding their design temperature.

4.3.1 Cross Section of High Density 8 Pole – 36 Slot Machine With a 8.75" Stack

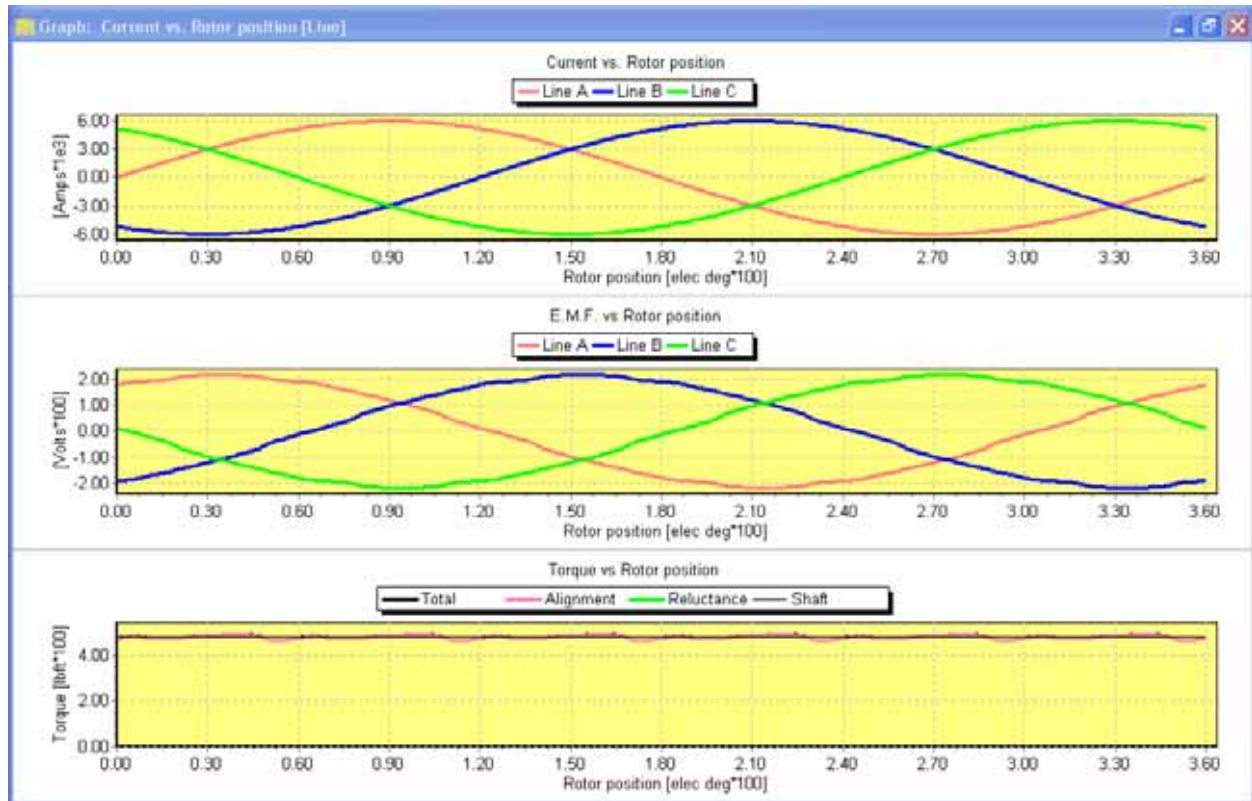


1.011 MW Output @ 15,000 rpm, 207 VDC rectified

Total Losses = 9921 W, Efficiency = 99%

Copper Losses = 4910 W Iron Losses = 4683 W Rotor Losses = 328 W

4.3.2 Simulated Output Curves @ 15,000 RPM



The back emf is quite sinusoidal which produces very little torque ripple to drive the generator.

5.0 Summary

The original calculations in section 3 were used to size the unit based upon the spec dimensions, the required performance, the maximum rotor diameter for 15,000 rpm and safe thermal assumptions based upon experience. The first motor modeled in section 4.1 was intended to be based upon the sizing. However it soon became apparent that for the stator/rotor lengths and rotor diameter selected the stator O.D. could be reduced from the maximum of 13.50" to 12.00". Even then the results indicated that the yoke was too thick with the copper and iron losses about equal.

Section 4.2 shows the results of a smaller stator (11.50" O.D.) and higher core losses but much lower copper losses. The cross section even looks more reasonable. Both models, the original and this one with the 24 slot stator and 8 poles, exhibited a sort of line to line trapezoid back emf which would cause significant torque which might make the turbine unhappy. So we simply skewed the stator stack from one end to the other a single slot. The result is very low torque ripple and a very nice sine back emf as shown in 4.2.2.

Even with these results it was suspected that if a higher density could be properly cooled a shorter unit might be feasible. Therefore continued simulations were tried until the results shown in section 4.3.1 resulted. The number of slots was increased from 24 to 36 and the stack was reduced from 16" down to 8.75". The skew was removed as it is not required with this slot to pole configuration. The result is just as an efficient machine as the others in a much smaller package. The power density is almost doubled with about the same losses. The amount of heat to be removed is the same as the others but the surface area of the stator core that is in contact with the cooling jacket is less than the longer stack. However, is believed that this design is feasible to do this job.

SECTION NUMBER	PC-BDC FILE	POLES SLOTS	EFFICIENCY (%)	TOTAL LOSSES	ACTIVE WEIGHT
4.1	FLA240C.bd4	8P-14S	98.95	10808 W	430 lbs
4.2	FLA240CJIM24.bd4	8P-24S	99.05	9635 W	298 lbs
4.2	FLA240jim24SKEWED.BD4	8P-24S	99.01	10157W	301 lbs
4.3	FLA240CJIM36short.bd4	8P36S	99.05	9711 W	158 lbs

The weights do not include frames, shafts bearings etc. Only the active parts, such as the magnets, rotor yoke, stator lamination stack and copper, are included.

APPENDIX

This Appendix contains the input data used to generate the results for each machine design discussed in the main body of the report as well as the Design Sheet for each design. Version 6.5 of PC-BDC for Windows was used for machine design and analysis.

Material selections were made from the database supplied with SPEED for this effort and were the same across all of the designs. "Hiperco50 (7 mil)" was used for the stator, rotor, and shaft steels. "S-L 30MGO" was used for the permanent magnet material.

For each design, in the order presented in the main body, the Template Data input, the winding configuration, and the Design Sheet are shown in this Appendix. The Design Sheet presented for each design was calculated using the Static Analysis calculation in PC-BDC.

This Appendix was generated by the program monitor from AFRL/PRPG (Charles Kessler), as opposed to the report's authors, in order to enhance the basic report and further support its conclusions.

PC-BDC 6.5 for Windows - *FLA240C.bdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Motor configuration

Template Editor

Dimensions

Config	Normal	RotType	SurfPII	Poles	8	Slots	24
Lstk	16.0	Embed	Not	LM	0.26	S-Slot	Square
Rad3	6.0	Rad1	3.93	BetaM	150.0	SD	0.6
Stf	0.97	Inset	0.0787	MagWid	1.1417	SO	0.1
MOH	0.0	Bridge	0.0394	SOang	20.0	TWS	0.6095
RotorAng	0.0	RadSH	1.5	TGD	0.0394	Gap	0.07
Ecc	0.0						

Windings

WdgType	Custom	Throw	2	Offset	2	TC	1
NSH	70	PPATHS	8	Ext	0.0	Liner	0.01
WireSpec	BareDia	Wire	0.032	XET	0.725	InsThick	0.0012
Skew	0.0	wt	0.0757	ct Liner	0.2		

Control

RPM	15000.0	Vs	145.0	Drive	AC Volt	Connex	Wye
ISP	4500.0	DuCy	0.5	Sw_Ctl	Generator	delta	22.0
HBA	8.0	IChop	0.0	dq0	false	ISLA	2.0
HBlime	Constant	FixChop	No	Tol ISLA	Auto	Tol	8.0
EMFCalc	BLV	ChopType	Soft	RTorq	On	Dwell	0.0
alpha	0.0	CalcVwfm	None	doRevert	false	BreakIT	0

Basic design Magnetics Calc Options Thermal

PC-BDC 6.5 for Windows - *FLA240C.bdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Adjustment factor for BrT

Template Editor

Magnets

XBrT	1.0	XLM	1.0	Xkm_HB	0.0	Bk	0.0
------	-----	-----	-----	--------	-----	----	-----

Fringing (shape of Bgap)

Fringing	ON	XFringe	1.0	XBetaM	1.0	BgProfil	Full
ManType	Radial	RCore	Iron	NHx	21	NHxL	21

Leakage

Xrl	1.0	u LKG	0.0	bBsat	0.0	apEnd	1.0
-----	-----	-------	-----	-------	-----	-------	-----

Saturation of armature-reaction and stator teeth

CalcSatn	Fixed	XSatn	1.0	SatnTol	0.0	Xks	0.0
----------	-------	-------	-----	---------	-----	-----	-----

Inductance

XL	1.0	XCd	1.0	XCq	1.0	XLdiff	1.0
PSSlot	S-Closed	muPlug	1.0	Saliency	Auto	Lext	0.0
ETCalc	BDC 6.0	XLendt	1.0	CalcLdLq	Auto	SpreadSO	true

Resistance

X_R	1.0	Rext	0.0				
-----	-----	------	-----	--	--	--	--

Slotting, Cogging

SlotMod	No	CalcCogg	Off	PlotTooth	1	PlotPole	1
XSlotMod	1.0	XCogg	1.0	PlotYoke	1		

Other adjustment factors

X_EMF	1.0	XBgap	1.0	XBtpk	1.0	Xrm	0.5
ukCL	0.0	XTTarc	1.0	XRYoke	0.0	XSyoce	0.0
XTw	0.0	LamThk	0.006	ufz	0.0	NBGapm	Exact

Basic design Magnetics Calc Options Thermal

PC-BDC 6.5 for Windows - "FLA240C-bd4"

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Current probe position (see Display simulation result graphs)

Template Editor

Calculation options

C-Probe	Phase	WriteLoop	None	TSMIn	0.0	TSMMax	0.0
Vq	0.0	Rq	0.0	Vu	0.0	R_s	0.0
Lq	0.0	Rd	1.0	eDet	off	CalcVer	cv6
Splitter	false	Vz	0.0	Cdc	0.0		
Rdc	0.0	Ldc	0.0	Rac	0.0	Lac	0.0

Losses

WFeCalc	OC	XFe	1.0	LossFE	Mech	Xmb	1.0
Wf0	0.0	RPM0	1000.0	NWFT	1.0		
cWmb	false	a_mb	0.0	b_mb	0.0	c_mb	0.0

Can

CanStyle	Rotor	SCanThk	0.0197	SCanSecs	1	pc_SCan	2.5
pc_Mag	0.0	SCanOH1	0.0	SCanOH2	0.0	SCanTF	0.0
TCCMag	0.0	RCanThk	0.04	RCanSecs	32	pc_RCan	2.5
pc_Sh	0.0	RCanOH1	0.0	RCanOH2	0.0	RCanTF	0.0

Additional Winding Parameters

EndFill	0.5	WireSpec2	None				
NSH2	1	InsThk2	0.0	Ww2	0.0787	wb2	0.0787
WireSpecA	None	WireA	0.0787	wbA	0.0787	InsThkA	0.0
NSHA	1						
TopStick	false	TwjWid	0.0787	TwjLeg	0.1378	TwjThk	0.015
PhsWid	0.0787	PhsLeg	0.1378	PhsThk	0.0		
NumPoly	1	PolyOffs	1	NphtIn	1	Npht	0.0

FE Analysis Parameters

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - "FLA240C-bd4"

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Use DegCW, HTC, or Thermal circuit to calculate temp. rise

Template Editor

Thermal

TempCalc	DegCW	FixTMag	IterX	Wdg2Mag	0.8	Ambient	120.0
T_Mag	240.0	T_Wdg	240.0	T_Brg	120.0	T_Gap	240.0
DegCW	0.01	HTCcd	10.0	HTCshd	0.0	ThTol	1.0

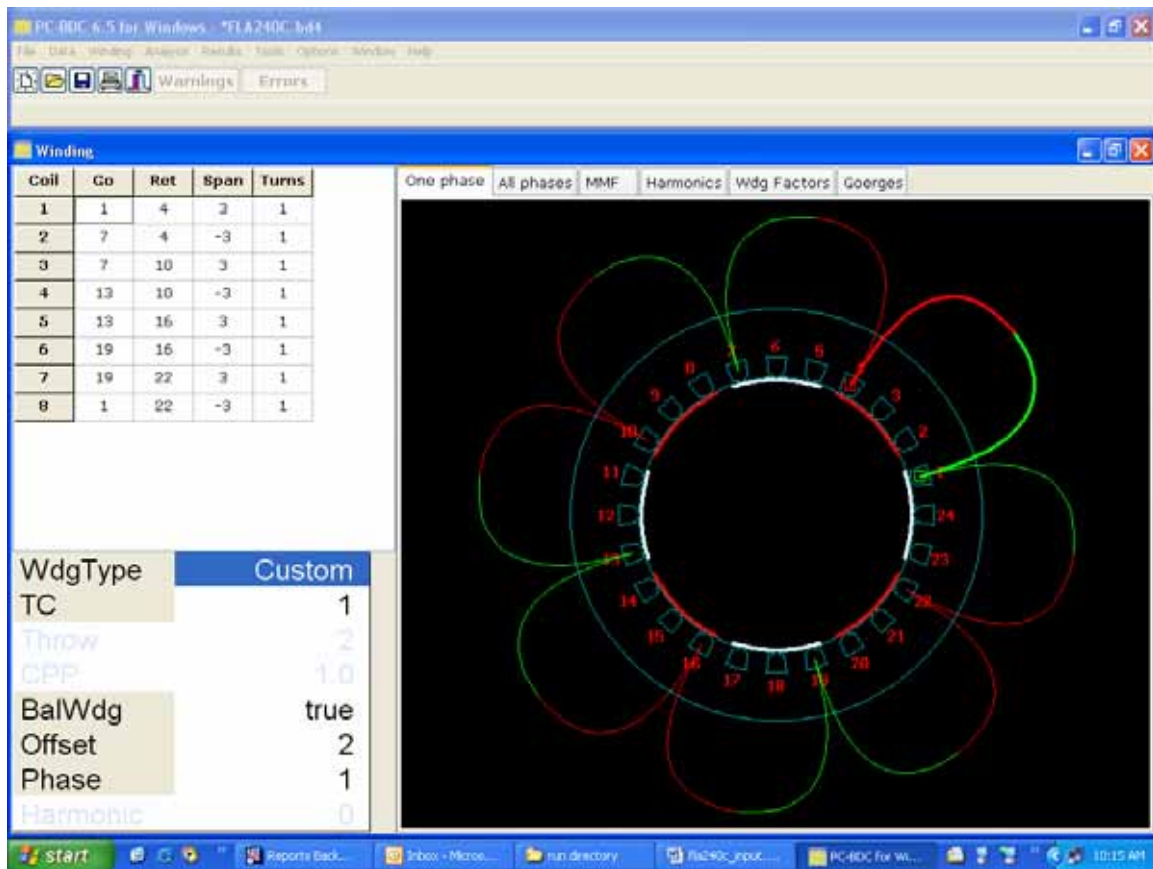
Specific heats and Additional thermal capacities...

cp_Frame	0.896	cp_SFe	0.45	cp_Cu	0.3831		
cp_Shft	0.45	cp_RFe	0.45	cp_Mag	0.45		
AddC_F	0.0	AddC_Y	0.0	AddC_Cu	0.0		
AddC_H	0.0	AddC_R	0.0	AddC_B	0.0		
AddC_T	0.0	AddC_M	0.0				

Additional dimensions needed for thermal model..

FrLgth	18.0	FrThk	0.1	FrDens	2700.0	CapThk	0.1
N_Fins	72.0	LFin	1.0	FinThk	0.25	XFSArea	1.0
LShaft	20.0	ShDens	7800.0				

Basic design / Magnetics / Calc. Options / Thermal



PC-BDC 6.5 for Windows (6.5.2.8) 3/8/2005 10:17:01 AM
C:\Documents and Settings\kesslecl\My Documents\Hendershot report\run
directory\FLA240CJIM24.bd4
Wright-Patterson AFB
PC-BDC main title
PC-BDC sub-title

1 Dimensions:-----

RotType	SurfP11	Embed	Not	Poles	8
StatorOD	11.500 in	LamShape	Circle	Slots	24
SYoke	0.750 in	ASD	1.000 in	SP	3.000
Rad3	5.750 in	Rad2	5.000 in	S-Slot	Square
TWS	0.610 in	SD	1.000 in	S0	0.100 in
TGD	0.039 in	S0ang	30.000 mDeg	Stf	0.970
Rotor..					
MOH	0.000 in	Nmbp	1	Skew	0.000
RotorOD	7.860 in	Rad1	3.930 in	Gap	0.070 in
LM	0.260 in	BetaM	150.000 eDeg	pupa	0.833
RYoke	0.770 in			RadSH	2.900 in
DHub	7.340 in	wNeck	0.303 in		
MEdge	0.276 in	LM_min	0.260 in		
wMag	2.527 in				
Lstk	16.000 in	Lrotor	16.000 in	Lstator	16.330 in

2 Magnet Data:-----

Magnet	S-L 30MGO				
Br	1.140 T	Hc	1100.000 kA/m	MuRec	1.020
CBr	-0.030 %/DegC	CHc	-0.220 %/DegC	DMag	8400.000 kg/m3
BrT	1.065 T	HcT	567.600 kA/m		
Nuisance	0.000 in	BrTnu	1.065 T	MuRecnu	1.020

3 Control Data:-----

RPM	15000.000 rpm	Vs	145.000 V	Drive	AC Volt
EMFCalc	BLV	delta	22.500 eDeg	Sw_Ctl	Generator

4 Winding Data:-----

Connex	Wye				
WdgType	Custom				
Offset	2	CPP	1.000		
Tph	1.000	PPATHS	8	SPP	1.000
Layers	2.000	CSidesPh	16	Z	48.000
MLT	39.473 in	Lgth0End	18.379 in	Ext	0.000 in
EndFill	0.500	LaxPack	17.396 in	Liner	9.000E-03 in
WireSpec	SFill	SFg	0.400		
NSH	70	WireDia	0.044 in	InsThick	1.150E-03 in
SFg	0.400	SFn	0.600	MaxSFn	0.593
Aslot	0.531 in^2	ASlotLL	0.499 in^2	ACond	0.106 in^2
GPAslot	0.535 in^2	ATstick	0.031 in^2	TopStick	false
TwjWid	0.079 in	TwjLeg	0.138 in	TwjThk	0.015 in
PhsWid	0.079 in	PhsLeg	0.138 in	PhsThk	0.000 in
ATwj	5.315E-03 in^2	APhs	0.000 in^2		
XET	0.725	ETCalc	BDC 6.0	Rext	0.000 ohm
Nse	1.273	X_R	1.000	Ax1	37.500 mDeg
T_Wdg	240.000 DegC	Rph0	5.881E-05 ohm	R_LL	1.176E-04 ohm
T_c	240.000 DegC	Rph	5.881E-05 ohm/ph	TFRho	1.865
Inductances...					
Lph	1.131E-03 mH	Mph	-0.000 mH	XL	1.000

Lg	6.237E-04	mH	LSlot	3.762E-04	mH	Lendt	1.309E-04	mH
Mg	-0.000	mH	MSlot	0.000	mH	LDiff	1.195E-04	mH
Lsigma	6.266E-04	mH	Msigma	4.423E-05	mH	XLdiff	1.000	
Lgg	2.780E-03	mH	Mgg	-0.001	mH	PCSlot	1.473	
LL_d	2.681E-03	mH	LL_q	2.674E-03	mH	L_LL	2.678E-03	mH
Lg_0	5.043E-04	mH	Lg_2	1.242E-06	mH	Laa_d	1.132E-03	mH
Ld	1.341E-03	mH	Lq	1.337E-03	mH	Laa_q	1.130E-03	mH
Xd	8.423E-03	ohm/ph	Xq	8.400E-03	ohm/ph	Xsigma	3.659E-03	ohm/ph
XCd	1.000		XCq	1.000		Lext	0.000	mH
Gd	0.216		Gq	0.215		XLendt	1.000	
kw1	1.000		Xm0	0.022	ohm/ph			
ks1	1.000		kp1	1.000		kd1	1.000	
ksg	0.811		fz	1.021		PSSlot	S-Closed	
Saliency	Auto		CalcLdLq	Auto		muPlug	1.000	
i1_Ang	-2829.896	A	i2_Ang	5659.793	A	i3_Ang	-2829.896	A

5 Magnetic Circuit Design:-----

T_Mag	240.000	DegC	T_r	240.000	DegC	XBrT	1.000	
BrT	1.065	T	BgOC	0.793	T	Hca	830.695	kA/m
BgAvOC	0.653	T	PhiG	21.004	mWb	BgA/BgOC	0.824	
Bg1OC	0.963	T	PhiM1	19.708	mWb	Bg1/BgOC	1.214	
BmOC	0.848	T	Bm/BrT	0.796		XBtpk	1.000	
HmOC	-169.305	kA/m	Hm/HcT	-0.298		PC	3.985	
Bst	1.313	T	Bsy	1.340	T	Bry	1.321	T
XTw	0.000		XS YOke	0.000		XRYoke	0.000	
kT	0.118	Nm/A	kE	0.129	Vs/Rad	krpmNL	15.000	krpm
kSat	1.000		XSatn	1.000		CalcSatn	Fixed	
Xks	0.000		ks	0.000		XTTarc	1.000	
EffWst	0.610	in	EffLst	0.847	in	ukCL	0.000	
XBgap	1.000		X_EMF	1.000		k_rpf	1.000	
eLLpk	203.002	V	eTmax	96.357	V	Bslot	8.723E-05	T
IBk	21943.644	A	Bk	0.000	T	Hk	-830.695	kA/m
ILR	1.233E+06	A	BmLR	-53.166	T	HmLR	-4.23E+04	kA/m
IC180	2.959E+06	A	BmC180	-128.948	T	HmC180	-1.01E+05	kA/m
BHmag	143.528	kJ/m3	Carter	1.005		Xrm	0.500	
Amhp	20.212	in^2	Aghp	20.761	in^2	Rghp	1.062E+05	At/Wb
Pm0	2.531	uWb/At	Xrl	1.000		prl	0.196	
apEnd	1.000		Pend	0.000		Lme	0.260	in
u_LKG	0.000		f_Lkg	0.950		if_Lkg	1.053	
Fringing	ON		XFringe	1.000		XBetaM	1.000	

6 Constant AC Volts static performance [phasor diagram]:-----

OpMode	Generating		Vs	145.000	V	RPM	15000.000	rpm
Tshaft	475.403	lbft	Pshaft	1.012E+06	W	Eff	98.918	%
WCu	2825.787	W	WFe	6304.168	W	WWF	0.000	W
WCan	504.936	W	WMagnet	0.000	W			
WTotal	9634.891	W	TempRise	120.000	DegC	Jrms	4711.357	A/in^2
IWpk	5659.793	A	IWav	3603.113	A	IWrms	4002.078	A
ILpk	5659.793	A	ILav	3603.113	A	ILrms	4002.078	A
IDC_P	6907.043	A	WFeCalc	OC		Pelec	1.002E+06	W
Eq1	87.561	V	Vph1	83.716	V	VLL1	145.000	V
Iph1	4002.078	A	Is	0.000	A			
Iq1	3822.197	A	Id1	1186.354	A	gammaACV	17.244	deg
Vq1	77.343	V	Vd1	32.037	V	delta	22.500	deg
Bg1Load	0.923	T	phi	-5.256	eDeg	PF	0.996	
Bqad	0.000	T	Phida1	1.272	mWb	Phiqa1	4.079	mWb
BmLoad	0.787	T	Bma	-0.061	T	Fda1	-400.535	At/gap
Tgap_PS	471.588	lbft	TEI_PS	471.438		Trel_PS	0.149	lbft
Tgap	472.206	lbft	Tei	472.056	lbft	Trel	0.149	lbft
Tloop	472.197	lbft						

Vd0 204.814 V Pelec 1.002E+06 W

8 Steady-State Thermal Model:-----

TempCalc	DegCW	FixTMag	IterX	Ambient	120.000	DegC
DegCW	1.000E-02	degC/W	HTCcyl	10.000	W/m2/C	HTCend
TempRise	120.000	DegC	T_c	240.000	DegC	T_r
T_f	240.000	DegC	T_y	240.000	DegC	HeatFlux
SlotPeri	2.829	in	Liner	9.000E-03	in	ct_Liner
SSArea	45.264	in^2	C_motor	112.517	kJ/C	ThRSlot
FSArea	883.997	in^2				1.631E-03
						C/W

9 Miscellaneous:-----

Weights...

wt_Cu	32.307	lb	wt_Fe	239.702	lb	wt_Mag	26.012	lb
wt_Tot	298.021	lb	wt_Shaft	142.800	lb	wt_Frame	39.567	lb
wt_FeS	170.983	lb	wt_FeR	68.719	lb	wt_RSS	238.360	lb
Inertia components...								
RotJ	0.506	kg-m2	RotJSS	0.509	kg-m2	RotJSh	0.176	kg-m2
RotJFe	0.220	kg-m2	RotJMag	0.110	kg-m2	LShaft	20.000	in
sigma	3.649	psi						
Wf0	0.000	W	RPM0	1000.000	rpm	NWFT	1.000	
Fringing	ON		XFringe	1.000		NHx	21	
CanStyle	Rotor		SCanThk	0.020	in	SCanSecs	1	
pc_Scan	2.500	%	pc_Mag	0.000	%	pc_Sh	0.000	%
Ecc	0.000		UMPavg	-1.08E-14	lb	UMPmax	5.174E-13	lb
TRFrms	530.076	lb	TRFavg	470.415	lb	TRFmax	681.964	lb
CForce	78962.668	lb				LamThk	6.000E-03	in
NLams	2587		pcLam	3.000	%	RFei	1.000E+06	

10 Core loss analysis:-----

WFeCalc	OC	LossFE	Mech	XFe	1.000
DFekgS	7480.246	kg/m^3	St.Steel	Hiperco 50 (7mil)	
DFekgR	7480.246	kg/m^3	Ro.Steel	Hiperco 50 (7mil)	
DFekgSh	7480.246	kg/m^3	Sh.Steel	Hiperco 50 (7mil)	
wt_Teeth	64.749	lb	wt_Yoke	106.234	lb
wt_Troot	23.007	lb			
Specific core losses...					
cFe_E60	0.053	W/lb	cFe_H60	1.254	W/lb
cFe_E_F	14.643	W/lb	cFe_H_F	20.900	W/lb
cFe_T_E	20.528	W/lb	cFe_T_H	16.671	W/lb
cFe_Y_E	11.364	W/lb	cFe_Y_H	17.250	W/lb
cFe_60	1.307	W/lb			
cFe_F	35.544	W/lb			
cFe_T	37.199	W/lb			
cFe_Y	28.613	W/lb			
Core loss analysis...					
WFe_T_E	1801.484	W	WFe_T_H	1463.003	W
WFe_Y_E	1207.200	W	WFe_Y_H	1832.481	W
WFe_T	3264.487	W			
WFe_Y	3039.681	W			

End of Design sheet-----

PC-BDC 6.5 for Windows - *FLA240C.BM24.kit

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Template Editor

Dimensions

Config	Normal	RotType	SurfPII	Poles	8	Slots	24
Lstk	16.0	Embed	Not	LM	0.26	S-Slot	Square
Rad3	5.75	Rad1	3.93	BetaM	150.0	SD	1.0
Stf	0.97	Insat	0.0787	MagWid	1.1417	SO	0.1
MOH	0.0	Badge	0.0394	SOang	30.0	TWS	0.6095
RotorAng	0.0	RadSH	2.9	TGD	0.0394	Gap	0.07
Ecc	0.0						

Windings

WdgType	Custom	Thrn	2	Offset	2	TC	1
NSH	70	PPATHS	8	Ext	0.0	Liner	0.009
WireSpec	SFill	SFg	0.4	XET	0.725	InsThick	0.0012
Skew	0.0	wt	0.0787	cl_Liner	0.2		

Control

RPM	15000.0	Vs	145.0	Drive	AC Volt	Connex	Wye
ISP	4500.0	DuCy	0.5	Sw_Ctl	Generator	delta	22.5
HBA	5.0	IChop	0.0	dq0	false	ISLA	2.0
HbType	Constant	FastChop	No	Tol_ISLA	Auto	Tol	8.0
EMFCalc	BLV	ChopType	Soft	RTorq	On	Dwell	0.0
alpha	0.0	CalcVwfm	None	doRevert	false	BreakIT	0

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM24.kit

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Adjustment factor for BrT

Template Editor

Magnets

XBrT	1.0	XLM	1.0	Xkm_HB	0.0	Bk	0.0
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Fringing (shape of Bgap)

Fringing	ON	XFringe	1.0	XBetaM	1.0	BgProfil	Full
ManType	Radial	RCore	Iron	NHx	21	NHxL	21

Leakage

Xrl	1.0	u_LKG	0.0	bBsat	0.0	apEnd	1.0
-----	-----	-------	-----	-------	-----	-------	-----

Saturation of armature-reaction and stator teeth

CalcSatn	Fixed	XSatn	1.0	SatnTol	0.0	Xks	0.0
----------	-------	-------	-----	---------	-----	-----	-----

Inductance

XL	1.0	XCd	1.0	XCq	1.0	XLdiff	1.0
PSSlot	S-Closed	imuPlug	1.0	Saliency	Auto	Lext	0.0
ETCalc	BDC 6.0	XLendT	1.0	CalcLdLq	Auto	SpreadSO	true

Resistance

X_R	1.0	Rext	0.0				
-----	-----	------	-----	--	--	--	--

Slotting, Cogging

SlotMod	No	CalcCogg	Off	PlotTooth	1	PlotPole	1
XSlotMod	1.0	XCogg	1.0	PlotYoke	1		

Other adjustment factors

X_EMF	1.0	XBgap	1.0	XBtpk	1.0	Xrm	0.5
ukCL	0.0	XTTarc	1.0	XRYoke	0.0	XSyoce	0.0
XTw	0.0	LamThk	0.006	ufz	0.0	HBCgdm	Exact

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - "FLA240C.BM24.b.H"

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Current probe position (see Display simulation result graphs)

Template Editor

Calculation options

C-Probe	Line	WriteLoop	None	TSMIn	0.0	TSMMax	0.0
Vq	0.0	Rq	0.0	Vu	0.0	R_s	0.0
Lq	0.0	Rd	1.0	eDet	off	CalcVer	cv6
Splitter	false	Vz	0.0	Cdc	0.0		
Rdc	0.0	Ldc	0.0	Rac	0.0	Lac	0.0

Losses

WFeCalc	OC	XFe	1.0	LossFE	Mech	Xmb	1.0
Wf0	0.0	RPM0	1000.0	NWFT	1.0		
cWmb	false	a_mb	0.0	b_mb	0.0	c_mb	0.0

Can

CanStyle	Rotor	SCanThk	0.0197	SCanSecs	1	pc_SCan	2.5
pc_Mag	0.0	SCanOH1	0.0	SCanOH2	0.0	SCanTF	0.0
TCCMag	0.0	RCanThk	0.04	RCanSecs	32	pc_RCan	2.5
pc_Sh	0.0	RCanOH1	0.0	RCanOH2	0.0	RCanTF	0.0

Additional Winding Parameters

EndFill	0.5	WireSpec2	None				
NSH2	1	InsThk2	0.0	Ww2	0.0787	wb2	0.0787
WireSpecA	None	WireA	0.0787	WwA	0.0787	InsThkA	0.0
NSHA	1						
TopStick	false	TwjWid	0.0787	TwjLeg	0.1378	TwjThk	0.015
PhsWid	0.0787	PhsLeg	0.1378	PhsThk	0.0		
NumPoly	1	PolyOffs	1	NphtLeg	1	NBp	0.0

FE Analysis Parameters

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - "FLA240C.BM24.b.H"

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Use DegCW, HTC, or Thermal circuit to calculate temp. rise

Template Editor

Thermal

TempCalc	DegCW	FixTMag	IterX	Wdg2Mag	0.8	Ambient	120.0
T_Mag	240.0	T_Wdg	240.0	T_Brg	120.0	T_Gap	240.0
DegCW	0.01	HTCcd	10.0	HTCshd	0.0	ThTol	1.0

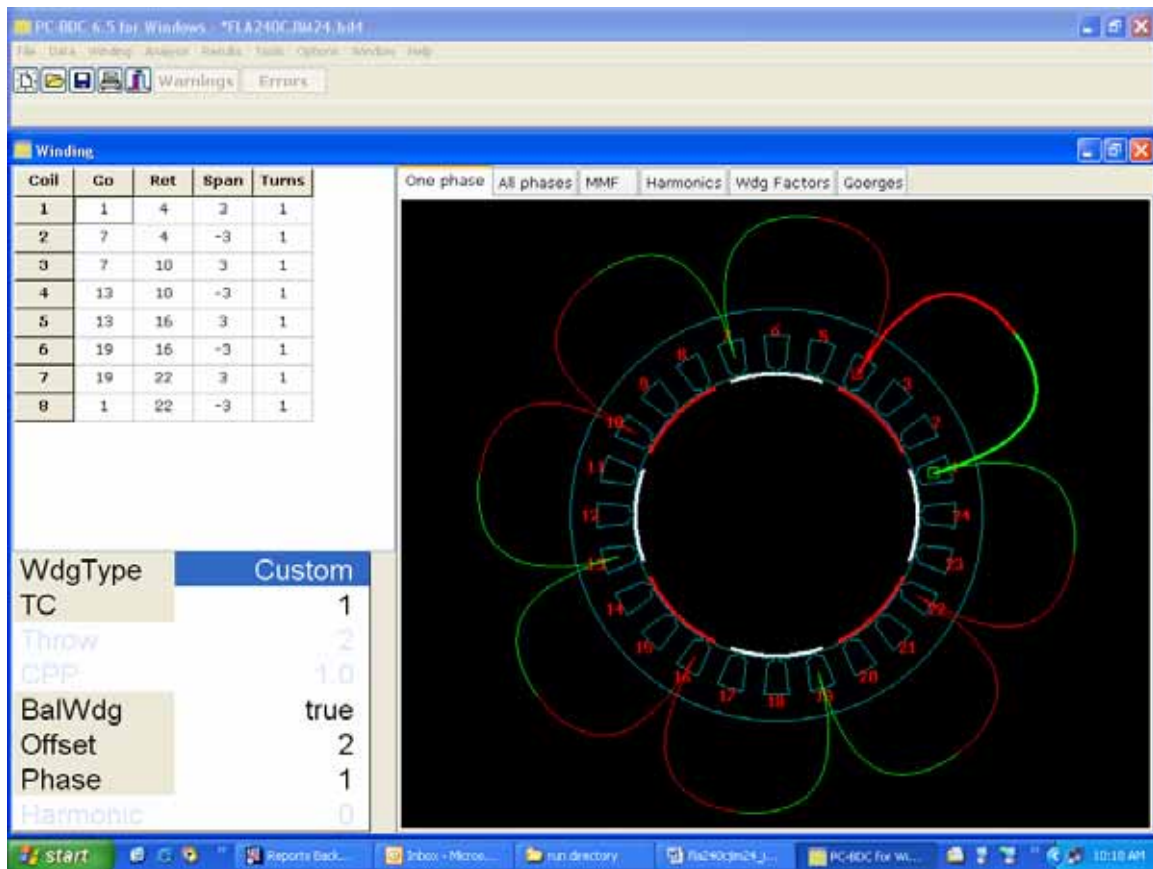
Specific heats and Additional thermal capacities...

cp_Frame	0.896	cp_SFe	0.45	cp_Cu	0.3831		
cp_Shaft	0.45	cp_RFe	0.45	cp_Mag	0.45		
AddC_F	0.0	AddC_Y	0.0	AddC_Cu	0.0		
AddC_H	0.0	AddC_R	0.0	AddC_B	0.0		
AddC_T	0.0	AddC_M	0.0				

Additional dimensions needed for thermal model..

FrLgth	18.0	FrThk	0.1	FrDens	2700.0	CapThk	0.1
N_Fins	72.0	LFin	1.0	FinThk	0.25	XFSArea	1.0
LShaft	20.0	ShDens	7800.0				

Basic design / Magnetics / Calc. Options / Thermal



PC-BDC 6.5 for Windows (6.5.2.8) 3/8/2005 10:17:01 AM
C:\Documents and Settings\kesslecl\My Documents\Hendershot report\run
directory\FLA240CJIM24.bd4
Wright-Patterson AFB
PC-BDC main title
PC-BDC sub-title

1 Dimensions:-----

RotType	SurfP11	Embed	Not	Poles	8
Stator..					
StatorOD	11.500 in	LamShape	Circle	Slots	24
SYoke	0.750 in	ASD	1.000 in	SP	3.000
Rad3	5.750 in	Rad2	5.000 in	S-Slot	Square
TWS	0.610 in	SD	1.000 in	S0	0.100 in
TGD	0.039 in	S0ang	30.000 mDeg	Stf	0.970
Rotor..					
MOH	0.000 in	Nmbp	1	Skew	0.000
RotorOD	7.860 in	Rad1	3.930 in	Gap	0.070 in
LM	0.260 in	BetaM	150.000 eDeg	pupa	0.833
RYoke	0.770 in			RadSH	2.900 in
DHub	7.340 in	wNeck	0.303 in		
MEdge	0.276 in	LM_min	0.260 in		
wMag	2.527 in				
Lstk	16.000 in	Lrotor	16.000 in	Lstator	16.330 in

2 Magnet Data:-----

Magnet	S-L 30MGO				
Br	1.140 T	Hc	1100.000 kA/m	MuRec	1.020
CBr	-0.030 %/DegC	CHc	-0.220 %/DegC	DMag	8400.000 kg/m3
BrT	1.065 T	HcT	567.600 kA/m		
Nuisance	0.000 in	BrTnu	1.065 T	MuRecnu	1.020

3 Control Data:-----

RPM	15000.000 rpm	Vs	145.000 V	Drive	AC Volt
EMFCalc	BLV	delta	22.500 eDeg	Sw_Ctl	Generator

4 Winding Data:-----

Connex	Wye				
WdgType	Custom				
Offset	2	CPP	1.000		
Tph	1.000	PPATHS	8	SPP	1.000
Layers	2.000	CSidesPh	16	Z	48.000
MLT	39.473 in	Lgth0End	18.379 in	Ext	0.000 in
EndFill	0.500	LaxPack	17.396 in	Liner	9.000E-03 in
WireSpec	SFill	SFg	0.400		
NSH	70	WireDia	0.044 in	InsThick	1.150E-03 in
SFg	0.400	SFn	0.600	MaxSFn	0.593
Aslot	0.531 in^2	ASlotLL	0.499 in^2	ACond	0.106 in^2
GPAslot	0.535 in^2	ATstick	0.031 in^2	TopStick	false
TwjWid	0.079 in	TwjLeg	0.138 in	TwjThk	0.015 in
PhsWid	0.079 in	PhsLeg	0.138 in	PhsThk	0.000 in
ATwj	5.315E-03 in^2	APhs	0.000 in^2		
XET	0.725	ETCalc	BDC 6.0	Rext	0.000 ohm
Nse	1.273	X_R	1.000	Ax1	37.500 mDeg
T_Wdg	240.000 DegC	Rph0	5.881E-05 ohm	R_LL	1.176E-04 ohm
T_c	240.000 DegC	Rph	5.881E-05 ohm/ph	TFRho	1.865
Inductances...					
Lph	1.131E-03 mH	Mph	-0.000 mH	XL	1.000

Lg	6.237E-04	mH	LSlot	3.762E-04	mH	Lendt	1.309E-04	mH
Mg	-0.000	mH	MSlot	0.000	mH	LDiff	1.195E-04	mH
Lsigma	6.266E-04	mH	Msigma	4.423E-05	mH	XLdiff	1.000	
Lgg	2.780E-03	mH	Mgg	-0.001	mH	PCSlot	1.473	
LL_d	2.681E-03	mH	LL_q	2.674E-03	mH	L_LL	2.678E-03	mH
Lg_0	5.043E-04	mH	Lg_2	1.242E-06	mH	Laa_d	1.132E-03	mH
Ld	1.341E-03	mH	Lq	1.337E-03	mH	Laa_q	1.130E-03	mH
Xd	8.423E-03	ohm/ph	Xq	8.400E-03	ohm/ph	Xsigma	3.659E-03	ohm/ph
XCd	1.000		XCq	1.000		Lext	0.000	mH
Gd	0.216		Gq	0.215		XLendt	1.000	
kw1	1.000		Xm0	0.022	ohm/ph			
ks1	1.000		kp1	1.000		kd1	1.000	
ksg	0.811		fz	1.021		PSSlot	S-Closed	
Saliency	Auto		CalcLdLq	Auto		muPlug	1.000	
i1_Ang	-2829.896	A	i2_Ang	5659.793	A	i3_Ang	-2829.896	A

5 Magnetic Circuit Design:-----

T_Mag	240.000	DegC	T_r	240.000	DegC	XBrT	1.000	
BrT	1.065	T	BgOC	0.793	T	Hca	830.695	kA/m
BgAvOC	0.653	T	PhiG	21.004	mWb	BgA/BgOC	0.824	
Bg1OC	0.963	T	PhiM1	19.708	mWb	Bg1/BgOC	1.214	
BmOC	0.848	T	Bm/BrT	0.796		XBtpk	1.000	
HmOC	-169.305	kA/m	Hm/HcT	-0.298		PC	3.985	
Bst	1.313	T	Bsy	1.340	T	Bry	1.321	T
XTw	0.000		XS YOke	0.000		XRYoke	0.000	
kT	0.118	Nm/A	kE	0.129	Vs/Rad	krpmNL	15.000	krpm
kSat	1.000		XSatn	1.000		CalcSatn	Fixed	
Xks	0.000		ks	0.000		XTTarc	1.000	
EffWst	0.610	in	EffLst	0.847	in	ukCL	0.000	
XBgap	1.000		X_EMF	1.000		k_rpf	1.000	
eLLpk	203.002	V	eTmax	96.357	V	Bslot	8.723E-05	T
IBk	21943.644	A	Bk	0.000	T	Hk	-830.695	kA/m
ILR	1.233E+06	A	BmLR	-53.166	T	HmLR	-4.23E+04	kA/m
IC180	2.959E+06	A	BmC180	-128.948	T	HmC180	-1.01E+05	kA/m
BHmag	143.528	kJ/m3	Carter	1.005		Xrm	0.500	
Amhp	20.212	in^2	Aghp	20.761	in^2	Rghp	1.062E+05	At/Wb
Pm0	2.531	uWb/At	Xrl	1.000		prl	0.196	
apEnd	1.000		Pend	0.000		Lme	0.260	in
u_LKG	0.000		f_Lkg	0.950		if_Lkg	1.053	
Fringing	ON		XFringe	1.000		XBetaM	1.000	

6 Constant AC Volts static performance [phasor diagram]:-----

OpMode	Generating		Vs	145.000	V	RPM	15000.000	rpm
Tshaft	475.403	lbft	Pshaft	1.012E+06	W	Eff	98.918	%
WCu	2825.787	W	WFe	6304.168	W	WWF	0.000	W
WCan	504.936	W	WMagnet	0.000	W			
WTotal	9634.891	W	TempRise	120.000	DegC	Jrms	4711.357	A/in^2
IWpk	5659.793	A	IWav	3603.113	A	IWrms	4002.078	A
ILpk	5659.793	A	ILav	3603.113	A	ILrms	4002.078	A
IDC_P	6907.043	A	WFeCalc	OC		Pelec	1.002E+06	W
Eq1	87.561	V	Vph1	83.716	V	VLL1	145.000	V
Iph1	4002.078	A	Is	0.000	A			
Iq1	3822.197	A	Id1	1186.354	A	gammaACV	17.244	deg
Vq1	77.343	V	Vd1	32.037	V	delta	22.500	deg
Bg1Load	0.923	T	phi	-5.256	eDeg	PF	0.996	
Bqad	0.000	T	Phida1	1.272	mWb	Phiqa1	4.079	mWb
BmLoad	0.787	T	Bma	-0.061	T	Fda1	-400.535	At/gap
Tgap_PS	471.588	lbft	TEI_PS	471.438		Trel_PS	0.149	lbft
Tgap	472.206	lbft	Tei	472.056	lbft	Trel	0.149	lbft
Tloop	472.197	lbft						

Vd0 204.814 V Pelec 1.002E+06 W

8 Steady-State Thermal Model:-----

TempCalc	DegCW	FixTMag	IterX	Ambient	120.000	DegC		
DegCW	1.000E-02	degC/W	HTCcyl	10.000	W/m2/C	HTCend	0.000	W/m2/C
TempRise	120.000	DegC	T_c	240.000	DegC	T_r	240.000	DegC
T_f	240.000	DegC	T_y	240.000	DegC	HeatFlux	0.000	kw/m^2
SlotPeri	2.829	in	Liner	9.000E-03	in	ct_Liner	0.200	W/mC
SSArea	45.264	in^2	C_motor	112.517	kJ/C	ThRSlot	1.631E-03	C/W
FSArea	883.997	in^2						

9 Miscellaneous:-----

Weights...

wt_Cu	32.307	lb	wt_Fe	239.702	lb	wt_Mag	26.012	lb
wt_Tot	298.021	lb	wt_Shaft	142.800	lb	wt_Frame	39.567	lb
wt_FeS	170.983	lb	wt_FeR	68.719	lb	wt_RSS	238.360	lb
Inertia components...								
RotJ	0.506	kg-m2	RotJSS	0.509	kg-m2	RotJSh	0.176	kg-m2
RotJFe	0.220	kg-m2	RotJMag	0.110	kg-m2	LShaft	20.000	in
sigma	3.649	psi						
Wf0	0.000	W	RPM0	1000.000	rpm	NWFT	1.000	
Fringing	ON		XFringe	1.000		NHx	21	
CanStyle	Rotor		SCanThk	0.020	in	SCanSecs	1	
pc_Scan	2.500	%	pc_Mag	0.000	%	pc_Sh	0.000	%
Ecc	0.000		UMPavg	-1.08E-14	lb	UMPmax	5.174E-13	lb
TRFrms	530.076	lb	TRFavg	470.415	lb	TRFmax	681.964	lb
CForce	78962.668	lb				LamThk	6.000E-03	in
NLams	2587		pcLam	3.000	%	RFei	1.000E+06	

10 Core loss analysis:-----

WFeCalc	OC	LossFE	Mech	XFe	1.000			
DFekgS	7480.246	kg/m^3	St.Steel	Hiperco 50 (7mil)				
DFekgR	7480.246	kg/m^3	Ro.Steel	Hiperco 50 (7mil)				
DFekgSh	7480.246	kg/m^3	Sh.Steel	Hiperco 50 (7mil)				
wt_Teeth	64.749	lb	wt_Yoke	106.234	lb	wt_Troot	23.007	lb
Specific core losses...								
cFe_E60	0.053	W/lb	cFe_H60	1.254	W/lb	cFe_60	1.307	W/lb
cFe_E_F	14.643	W/lb	cFe_H_F	20.900	W/lb	cFe_F	35.544	W/lb
cFe_T_E	20.528	W/lb	cFe_T_H	16.671	W/lb	cFe_T	37.199	W/lb
cFe_Y_E	11.364	W/lb	cFe_Y_H	17.250	W/lb	cFe_Y	28.613	W/lb
Core loss analysis...								
WFe_T_E	1801.484	W	WFe_T_H	1463.003	W	WFe_T	3264.487	W
WFe_Y_E	1207.200	W	WFe_Y_H	1832.481	W	WFe_Y	3039.681	W

End of Design sheet-----

PC-BDC 6.5 for Windows - *FLA240C.BM24SKWTD.hdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Motor configuration

Template Editor

Dimensions

Config	Normal	RotType	SurfPll	Poles	8	Slots	24
Lstk	16.0	Embed	Not	LM	0.26	S-Slot	Square
Rad3	5.75	Rad1	3.93	BetaM	150.0	SD	1.0
Stf	0.97	Insat	0.0787	MagWid	1.1417	SO	0.1
MOH	0.25	Bridge	0.0394	SOang	30.0	TWS	0.6095
RotorAng	0.0	RadSH	2.9	TGD	0.0394	Gap	0.07
Ecc	0.0						

Windings

WdgType	Custom	Throw	2	Offset	2	TC	1
NSH	70	PPATHS	8	Ext	0.0	Liner	0.009
WireSpec	SFill	SFg	0.4	XET	0.725	InsThick	0.0012
Skew	1.0	etc	0.0787	cl_Liner	0.2		

Control

RPM	15000.0	Vs	141.4	Drive	AC Volt	Connex	Wye
ISP	4500.0	DvCy	0.5	Sw_Ctl	Generator	delta	24.0
HBA	5.0	IChop	0.0	dq0	false	ISLA	2.0
HbType	Constant	FastChop	No	Tol ISLA	Auto	Tol	8.0
EMFCalc	BLV	ChopType	Soft	RTorq	On	Dwell	0.0
alpha	0.0	CalcVwfm	None	doRevert	false	BreakIT	0

Basic design / Magnetics / Calc Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM24SKWTD.hdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Adjustment factor for BrT

Template Editor

Magnets

XBrT	1.0	XLM	1.0	Xkm_HB	0.0	Bk	0.0
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Fringing (shape of Bgap)

Fringing	ON	XFringe	1.0	XBetaM	1.0	BgProfil	Full
ManType	Radial	RCore	Iron	NHx	21	NHxL	21

Leakage

Xrl	1.0	u LKG	0.0	bBsat	0.0	apEnd	1.0
-----	-----	-------	-----	-------	-----	-------	-----

Saturation of armature-reaction and stator teeth

CalcSatn	Fixed	XSatn	1.0	SatnTol	0.0	Xks	0.0
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Inductance

XL	1.0	XCd	1.0	XCq	1.0	XLdiff	1.0
PSSlot	S-Closed	imuPlug	1.0	Saliency	Auto	Lext	0.0
ETCalc	BDC 6.0	XLendT	1.0	CalcLdLq	Auto	SpreadSO	true

Resistance

X_R	1.0	Rext	0.0				
-----	-----	------	-----	--	--	--	--

Slotting, Cogging

SlotMod	No	CalcCogg	Off	PlotTooth	1	PlotPole	1
XSlotMod	1.0	XCogg	1.0	PlotYoke	1		

Other adjustment factors

X_EMF	1.0	XBgap	1.0	XBtpk	1.0	Xrm	0.5
ukCL	0.0	XTTarc	1.0	XRYoke	0.0	XSyoce	0.0
XTw	0.0	LamThk	0.006	ufz	0.0	HBGadm	Exact

Basic design / Magnetics / Calc Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM24SRWTD.hdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Current probe position (see Display simulation result graphs)

Template Editor

Calculation options

C-Probe	Line	WriteLoop	None	TSMIn	0.0	TSMMax	0.0
Vq	0.0	Rq	0.0	Vu	0.0	R_s	0.0
Lq	0.0	Rd	1.0	eDet	off	CalcVer	cv6
Splitter	false	Vz	0.0	Cdc	0.0		
Rdc	0.0	Ldc	0.0	Rac	0.0	Lac	0.0

Losses

WFeCalc	OC	XFe	1.0	LossFE	Mech	Xmb	1.0
Wf0	0.0	RPM0	1000.0	NWFT	1.0		
cWmb	false	a_mb	0.0	b_mb	0.0	c_mb	0.0

Can

CanStyle	Rotor	SCanThk	0.0197	SCanSecs	1	pc_SCan	2.5
pc_Mag	0.0	SCanOH1	0.0	SCanOH2	0.0	SCanTF	0.0
TCCMag	0.0	RCanThk	0.04	RCanSecs	32	pc_RCan	2.5
pc_Sh	0.0	RCanOH1	0.0	RCanOH2	0.0	RCanTF	0.0

Additional Winding Parameters

EndFill	0.5	WireSpec2	None				
NSH2	1	InsThk2	0.0	Ww2	0.0787	wb2	0.0787
WireSpecA	None	WireA	0.0787	WwA	0.0787	InsThkA	0.0
NSHA	1						
TopStick	false	TwjWid	0.0787	TwjLeg	0.1378	TwjThk	0.015
PhsWid	0.0787	PhsLeg	0.1378	PhsThk	0.0		
NumPoly	1	PolyOffs	1	NgthLeg	1	Ngth	0.0

FE Analysis Parameters

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM24SRWTD.hdt

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Use DegCW, HTC, or Thermal circuit to calculate temp. rise

Template Editor

Thermal

TempCalc	DegCW	FixTMag	IterX	Wdg2Mag	0.8	Ambient	120.0
T_Mag	240.0	T_Wdg	240.0	T_Brg	120.0	T_Gap	240.0
DegCW	0.01	HTCcd	10.0	HTCshd	0.0	ThTol	1.0

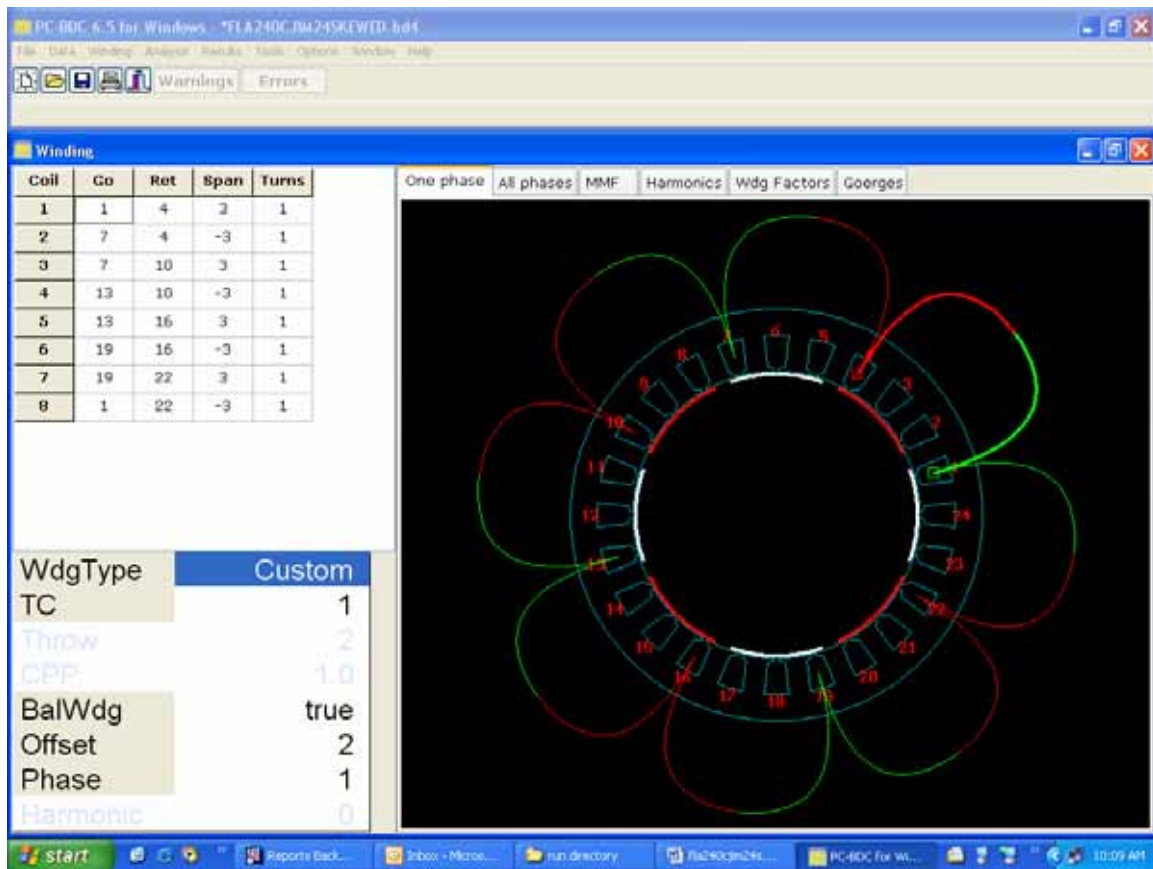
Specific heats and Additional thermal capacities...

cp_Frame	0.896	cp_SFe	0.45	cp_Cu	0.3831		
cp_Shft	0.45	cp_RFe	0.45	cp_Mag	0.45		
AddC_F	0.0	AddC_Y	0.0	AddC_Cu	0.0		
AddC_H	0.0	AddC_R	0.0	AddC_B	0.0		
AddC_T	0.0	AddC_M	0.0				

Additional dimensions needed for thermal model..

FrLgth	18.0	FrThk	0.1	FrDens	2700.0	CapThk	0.1
N_Fins	72.0	LFin	1.0	FinThk	0.25	XFSArea	1.0
LShaft	20.0	ShDens	7800.0				

Basic design / Magnetics / Calc. Options / Thermal



PC-BDC 6.5 for Windows (6.5.2.8) 3/8/2005 10:03:15 AM
C:\Documents and Settings\kesslecl\My Documents\Hendershot report\run
directory\FLA240CJIM24SKEWED.bd4
Wright-Patterson AFB
PC-BDC main title
PC-BDC sub-title

1 Dimensions:-----

RotType	SurfP11	Embed	Not	Poles	8
StatorOD	11.500 in	LamShape	Circle	Slots	24
SYoke	0.750 in	ASD	1.000 in	SP	3.000
Rad3	5.750 in	Rad2	5.000 in	S-Slot	Square
TWS	0.610 in	SD	1.000 in	S0	0.100 in
TGD	0.039 in	S0ang	30.000 mDeg	Stf	0.970
RotorOD	0.250 in	Nmbp	1	Skew	1.000
MOH	7.860 in	Rad1	3.930 in	Gap	0.070 in
LM	0.260 in	BetaM	150.000 eDeg	pupa	0.833
RYoke	0.770 in			RadSH	2.900 in
DHub	7.340 in	wNeck	0.303 in		
MEdge	0.276 in	LM_min	0.260 in		
wMag	2.527 in				
Lstk	16.000 in	Lrotor	16.500 in	Lstator	16.330 in

2 Magnet Data:-----

Magnet	S-L 30MGO				
Br	1.140 T	Hc	1100.000 kA/m	MuRec	1.020
CBr	-0.030 %/DegC	CHc	-0.220 %/DegC	DMag	8400.000 kg/m3
BrT	1.065 T	HcT	567.600 kA/m		
Nuisance	0.000 in	BrTnu	1.065 T	MuRecnu	1.020

3 Control Data:-----

RPM	15000.000 rpm	Vs	141.400 V	Drive	AC Volt
EMFCalc	BLV	delta	24.000 eDeg	Sw_Ctl	Generator

4 Winding Data:-----

Connex	Wye				
WdgType	Custom				
Offset	2	CPP	1.000		
Tph	1.000	PPATHS	8	SPP	1.000
Layers	2.000	CSidesPh	16	Z	48.000
MLT	39.473 in	Lgth0End	18.379 in	Ext	0.000 in
EndFill	0.500	LaxPack	17.396 in	Liner	9.000E-03 in
WireSpec	SFill	SFg	0.400		
NSH	70	WireDia	0.044 in	InsThick	1.150E-03 in
SFg	0.400	SFn	0.600	MaxSFn	0.593
Aslot	0.531 in^2	ASlotLL	0.499 in^2	ACond	0.106 in^2
GPAslot	0.535 in^2	ATstick	0.031 in^2	TopStick	false
TwjWid	0.079 in	TwjLeg	0.138 in	TwjThk	0.015 in
PhsWid	0.079 in	PhsLeg	0.138 in	PhsThk	0.000 in
ATwj	5.315E-03 in^2	APhs	0.000 in^2		
XET	0.725	ETCalc	BDC 6.0	Rext	0.000 ohm
Nse	1.216	X_R	1.000	Ax1	45.000 mDeg
T_Wdg	240.000 DegC	Rph0	5.881E-05 ohm	R_LL	1.176E-04 ohm
T_c	240.000 DegC	Rph	5.881E-05 ohm/ph	TFRho	1.865
Inductances...					
Lph	1.131E-03 mH	Mph	-0.000 mH	XL	1.000

Lg	6.237E-04	mH	LSlot	3.762E-04	mH	Lendt	1.309E-04	mH
Mg	-0.000	mH	MSlot	0.000	mH	LDiff	1.639E-04	mH
Lsigma	6.710E-04	mH	Msigma	2.201E-05	mH	XLdiff	1.000	
Lgg	2.780E-03	mH	Mgg	-0.001	mH	PCSlot	1.473	
LL_d	2.681E-03	mH	LL_q	2.674E-03	mH	L_LL	2.678E-03	mH
Lg_0	4.599E-04	mH	Lg_2	1.132E-06	mH	Laa_d	1.132E-03	mH
Ld	1.340E-03	mH	Lq	1.337E-03	mH	Laa_q	1.130E-03	mH
Xd	8.422E-03	ohm/ph	Xq	8.401E-03	ohm/ph	Xsigma	4.078E-03	ohm/ph
XCd	1.000		XCq	1.000		Lext	0.000	mH
Gd	0.216		Gq	0.215		XLendt	1.000	
kw1	0.955		Xm0	0.020	ohm/ph			
ks1	0.955		kp1	1.000		kd1	1.000	
ksg	0.739		fz	1.021		PSSlot	S-Closed	
Saliency	Auto		CalcLdLq	Auto		muPlug	1.000	
i1_Ang	7.216E-13	A	i2_Ang	5102.866	A	i3_Ang	-5102.866	A

5 Magnetic Circuit Design:-----

T_Mag	240.000	DegC	T_r	240.000	DegC	XBrT	1.000	
BrT	1.065	T	BgOC	0.813	T	Hca	830.695	kA/m
BgAvOC	0.670	T	PhiG	21.523	mWb	BgA/BgOC	0.824	
Bg1OC	0.987	T	PhiM1	20.196	mWb	Bg1/BgOC	1.214	
BmOC	0.842	T	Bm/BrT	0.791		XBtpk	1.000	
HmOC	-173.483	kA/m	Hm/HcT	-0.306		PC	3.864	
Bst	1.342	T	Bsy	1.370	T	Bry	1.354	T
XTw	0.000		XS YOke	0.000		XRYoke	0.000	
kT	0.116	Nm/A	kE	0.132	Vs/Rad	krpmNL	15.000	krpm
kSat	1.000		XSatn	1.000		CalcSatn	Fixed	
Xks	0.000		ks	0.000		XTTarc	1.000	
EffWst	0.610	in	EffLst	0.847	in	ukCL	0.000	
XBgap	1.000		X_EMF	1.000		k_rpf	1.000	
eLLpk	207.794	V	eTmax	75.364	V	Bslot	8.995E-05	T
IBk	21943.644	A	Bk	0.000	T	Hk	-830.695	kA/m
ILR	1.202E+06	A	BmLR	-51.239	T	HmLR	-4.08E+04	kA/m
IC180	2.969E+06	A	BmC180	-127.937	T	HmC180	-1.01E+05	kA/m
BHmag	146.141	kJ/m3	Carter	1.005		Xrm	0.500	
Amhp	20.844	in^2	Aghp	20.761	in^2	Rghp	1.062E+05	At/Wb
Pm0	2.610	uWb/At	Xrl	1.000		prl	0.190	
apEnd	1.000		Pend	0.000		Lme	0.260	in
u_LKG	0.000		f_Lkg	0.950		if_Lkg	1.053	
Fringing	ON		XFringe	1.000		XBetaM	1.000	

6 Constant AC Volts static performance [phasor diagram]:-----

OpMode	Generating		Vs	141.400	V	RPM	15000.000	rpm
Tshaft	481.992	lbft	Pshaft	1.027E+06	W	Eff	98.935	%
WCu	3062.707	W	WFe	6564.507	W	WWF	0.000	W
WCan	530.223	W	WMagnet	0.000	W			
WTotal	10157.437	W	TempRise	120.000	DegC	Jrms	4904.887	A/in^2
IWpk	5892.282	A	IWav	3751.120	A	IWrms	4166.473	A
ILpk	5892.282	A	ILav	3751.120	A	ILrms	4166.473	A
IDC_P	7182.242	A	WFeCalc	OC		Pelec	1.016E+06	W
Eq1	85.683	V	Vph1	81.637	V	VLL1	141.400	V
Iph1	4166.473	A	Is	0.000	A			
Iq1	3961.518	A	Id1	1290.684	A	gammaACV	18.046	deg
Vq1	74.579	V	Vd1	33.205	V	delta	24.000	deg
Bg1Load	0.943	T	phi	-5.954	eDeg	PF	0.995	
Bqad	0.000	T	Phida1	1.322	mWb	Phiqa1	4.037	mWb
BmLoad	0.779	T	Bma	-0.063	T	Fda1	-416.119	At/gap
Tgap_PS	478.295	lbft	TEI_PS	478.141		Trel_PS	0.154	lbft
Tgap	478.661	lbft	Tei	478.507	lbft	Trel	0.154	lbft
Tloop	478.652	lbft						

Vd0 200.420 V Pelec 1.016E+06 W

8 Steady-State Thermal Model:-----

TempCalc	DegCW	FixTMag	IterX	Ambient	120.000	DegC
DegCW	1.000E-02	degC/W	HTCcyl	10.000	W/m2/C	HTCend
TempRise	120.000	DegC	T_c	240.000	DegC	T_r
T_f	240.000	DegC	T_y	240.000	DegC	HeatFlux
SlotPeri	2.829	in	Liner	9.000E-03	in	ct_Liner
SSArea	45.264	in^2	C_motor	113.121	kJ/C	ThRSlot
FSArea	883.997	in^2				1.631E-03
						C/W

9 Miscellaneous:-----

Weights...

wt_Cu	32.307	lb	wt_Fe	241.850	lb	wt_Mag	26.825	lb
wt_Tot	300.982	lb	wt_Shaft	142.800	lb	wt_Frame	39.567	lb
wt_FeS	170.983	lb	wt_FeR	70.867	lb	wt_RSS	241.347	lb
Inertia components...								
RotJ	0.516	kg-m2	RotJSS	0.520	kg-m2	RotJSh	0.176	kg-m2
RotJFe	0.227	kg-m2	RotJMag	0.113	kg-m2	LShaft	20.000	in
sigma	3.699	psi						
Wf0	0.000	W	RPM0	1000.000	rpm	NWFT	1.000	
Fringing	ON		XFringe	1.000		NHx	21	
CanStyle	Rotor		SCanThk	0.020	in	SCanSecs	1	
pc_Scan	2.500	%	pc_Mag	0.000	%	pc_Sh	0.000	%
Ecc	0.000		UMPavg	-5.78E-15	lb	UMPmax	3.134E-13	lb
TRFrms	514.345	lb	TRFavg	445.463	lb	TRFmax	716.117	lb
CForce	81430.252	lb				LamThk	6.000E-03	in
NLams	2587		pcLam	3.000	%	RFei	1.000E+06	

10 Core loss analysis:-----

WFeCalc	OC	LossFE	Mech	XFe	1.000
DFekgS	7480.246	kg/m^3	St.Steel	Hiperco 50 (7mil)	
DFekgR	7480.246	kg/m^3	Ro.Steel	Hiperco 50 (7mil)	
DFekgSh	7480.246	kg/m^3	Sh.Steel	Hiperco 50 (7mil)	
wt_Teeth	64.749	lb	wt_Yoke	106.234	lb
wt_Troot					23.007
Specific core losses...					
cFe_E60	0.053	W/lb	cFe_H60	1.254	W/lb
cFe_E_F	14.643	W/lb	cFe_H_F	20.900	W/lb
cFe_T_E	21.450	W/lb	cFe_T_H	17.305	W/lb
cFe_Y_E	11.874	W/lb	cFe_Y_H	17.905	W/lb
cFe_Y					29.779
Core loss analysis...					
WFe_T_E	1882.337	W	WFe_T_H	1518.631	W
WFe_Y_E	1261.381	W	WFe_Y_H	1902.158	W
WFe_T					3400.968
WFe_Y					3163.539

End of Design sheet-----

PC-BDC 6.5 for Windows - *FLA240C.BM36shurt.bd4

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Save Save

Template Editor

Dimensions

Config	Normal	RotType	SurfPIII	Poles	8	Slots	36
Lstk	8.75	Embed	Not	LM	0.26	S-Slot	Square
Rad3	5.75	Rad1	3.93	BetaM	150.0	SD	1.2
Stf	0.97	Insat	0.0787	MagWid	1.1417	SO	0.1
MOH	0.0	Bridge	0.0394	SOang	30.0	TWS	0.28
RotorAng	0.0	RadSH	2.9	TGD	0.0394	Gap	0.07
Ecc	0.0						

Windings

WdgType	Custom	Throw	4	Offset	3	TC	1
NSH	70	PPATHS	4	Ext	0.0	Liner	0.009
WireSpec	SFill	SFg	0.4	XET	0.725	InsThick	0.0012
Skew	0.0	wt	0.0787	cl_Liner	0.2		

Control

RPM	15000.0	Vs	146.0	Drive	AC Volt	Connex	Wye
ISP	4500.0	DvCy	0.5	Sw_Ctl	Generator	delta	46.0
HBA	5.0	IChop	0.0	dq0	false	ISLA	2.0
HbType	Constant	FstChop	No	Tol ISLA	Auto	Tol	8.0
EMFCalc	BLV	ChopType	Soft	RTorq	On	Dwell	0.0
alpha	0.0	CalcVwfm	None	doRevert	false	BreakIT	0

Basic design / Magnetics / Calc Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM36shurt.bd4

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Adjustment factor for BrT

Template Editor

Magnets

XBrT	1.0	XLM	1.0	Xkm_HB	0.0	Bk	0.0
------	-----	-----	-----	--------	-----	----	-----

Fringing (shape of Bgap)

Fringing	ON	XFringe	1.0	XBetaM	1.0	BgProfil	Full
IronType	Radial	RCore	Iron	NHx	21	NHxL	21

Leakage

Xrl	1.0	u LKG	0.0	bBsat	0.0	apEnd	1.0
-----	-----	-------	-----	-------	-----	-------	-----

Saturation of armature-reaction and stator teeth

CalcSatn	Fixed	XSatn	1.0	SatnTol	0.0	Xks	0.0
----------	-------	-------	-----	---------	-----	-----	-----

Inductance

XL	1.0	XCd	1.0	XCq	1.0	XLdiff	1.0
PSSlot	S-Closed	imuPlug	1.0	Saliency	Auto	Lext	0.0
ETCalc	BDC 6.0	XLendt	1.0	CalcLdLq	Auto	SpreadSO	true

Resistance

X_R	1.0	Rext	0.0				
-----	-----	------	-----	--	--	--	--

Slotting, Cogging

SlotMod	No	CalcCogg	Off	PlotTooth	1	PlotPole	1
XSlotMod	1.0	XCogg	1.0	PlotYoke	1		

Other adjustment factors

X_EMF	1.0	XBgap	1.0	XBtpk	1.0	Xrm	0.5
ukCL	0.0	XTTarc	1.0	XRYoke	0.0	XSyoce	0.0
XTw	0.0	LamThk	0.006	ufz	0.0	HBGadm	Exact

Basic design / Magnetics / Calc Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM36shurt.bdf

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Current probe position (see Display simulation result graphs)

Template Editor

Calculation options

C-Probe	Line	WriteLoop	None	TSMIn	0.0	TSMMax	0.0
Vq	0.0	Rq	0.0	Vu	0.0	R_s	0.0
Lq	0.0	Rd	1.0	eDet	off	CalcVer	cv6
Splitter	false	Vz	0.0	Cdc	0.0		
Rdc	0.0	Ldc	0.0	Rac	0.0	Lac	0.0

Losses

WFeCalc	OC	XFe	1.0	LossFE	Mech	Xmb	1.0
Wf0	0.0	RPM0	1000.0	NWFT	1.0		
cWmb	false	a mb	0.0	b mb	0.0	c mb	0.0

Can

CanStyle	Rotor	SCanThk	0.0197	SCanSecs	1	pc_SCan	2.5
pc_Mag	0.0	SCanOH1	0.0	SCanOH2	0.0	SCanTF	0.0
TCCMag	0.0	RCanThk	0.04	RCanSecs	32	pc_RCan	2.5
pc_Sh	0.0	RCanOH1	0.0	RCanOH2	0.0	RCanTF	0.0

Additional Winding Parameters

EndFill	0.5	WireSpec2	None				
NSH2	1	InsThk2	0.0	Ww2	0.0787	wb2	0.0787
WireSpecA	None	WireA	0.0787	WwA	0.0787	InsThkA	0.0
NSHA	1						
TopStick	false	TwjWid	0.0787	TwjLeg	0.1378	TwjThk	0.015
PhsWid	0.0787	PhsLeg	0.1378	PhsThk	0.0		
NumPoly	1	PolyOffs	1	NgthLeg	1	NB/L	0.0

FE Analysis Parameters

Basic design / Magnetics / Calc. Options / Thermal

PC-BDC 6.5 for Windows - *FLA240C.BM36shurt.bdf

File Data Template Analysis Results Tools Options Window Help

Warnings Errors

Use DegCW, HTC, or Thermal circuit to calculate temp. rise

Template Editor

Thermal

TempCalc	DegCW	FixTMag	IterX	Wdg2Mag	0.8	Ambient	120.0
T_Mag	240.0	T_Wdg	240.0	T_Brg	120.0	T_Gap	240.0
DegCW	0.01	HTCcd	10.0	HTCshd	0.0	ThTol	1.0

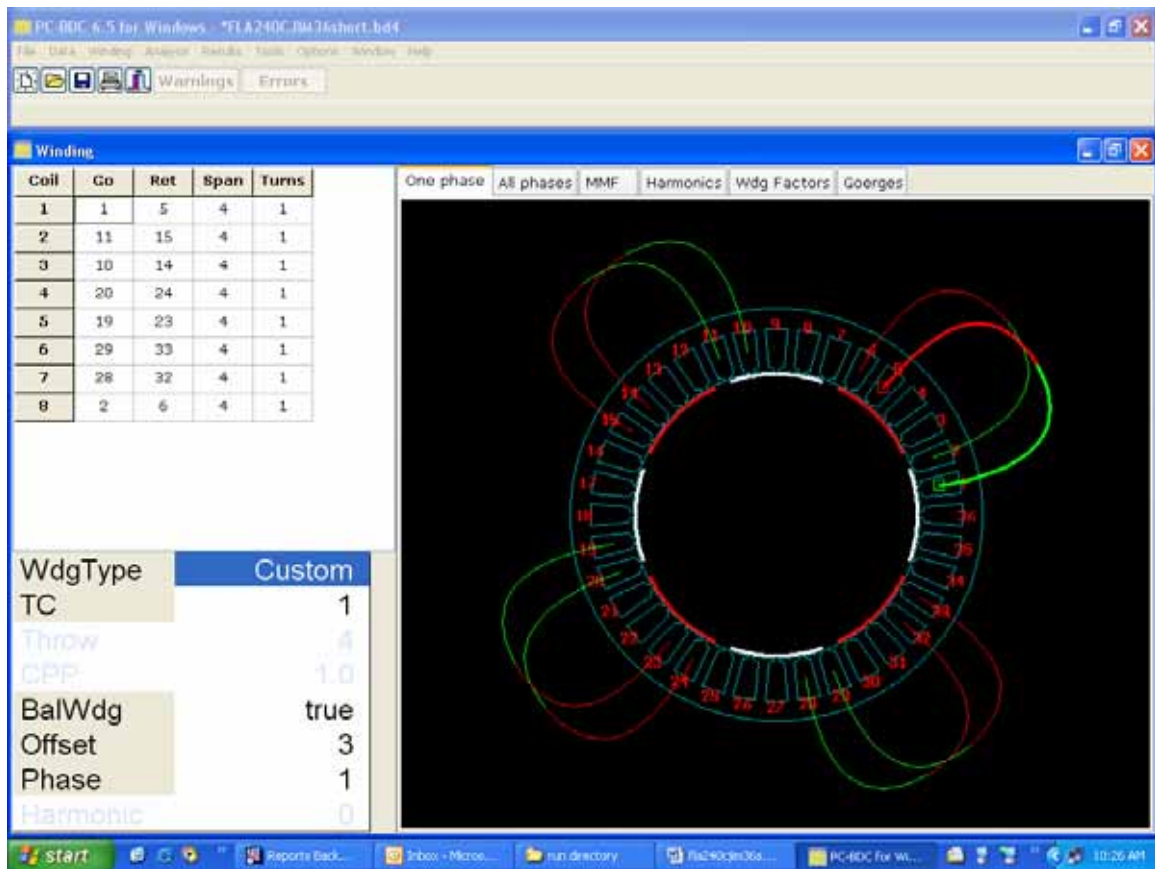
Specific heats and Additional thermal capacities...

cp_Frame	0.896	cp_SFe	0.45	cp_Cu	0.3831		
cp_Shft	0.45	cp_RFe	0.45	cp_Mag	0.45		
AddC_F	0.0	AddC_Y	0.0	AddC_Cu	0.0		
AddC_H	0.0	AddC_R	0.0	AddC_B	0.0		
AddC_T	0.0	AddC_M	0.0				

Additional dimensions needed for thermal model..

FrLgth	18.0	FrThk	0.1	FrDens	2700.0	CapThk	0.1
N_Fins	72.0	LFin	1.0	FinThk	0.25	XFSArea	1.0
LShaft	20.0	ShDens	7800.0				

Basic design / Magnetics / Calc. Options / Thermal



PC-BDC 6.5 for Windows (6.5.2.8) 3/8/2005 10:24:40 AM
C:\Documents and Settings\kesslecl\My Documents\Hendershot report\run
directory\FLA240CJIM36short.bd4
Wright-Patterson AFB
PC-BDC main title
PC-BDC sub-title

1 Dimensions:-----

RotType	SurfP11	Embed	Not	Poles	8
Stator..					
StatorOD	11.500 in	LamShape	Circle	Slots	36
SYoke	0.550 in	ASD	1.200 in	SP	4.500
Rad3	5.750 in	Rad2	5.200 in	S-Slot	Square
TWS	0.280 in	SD	1.200 in	S0	0.100 in
TGD	0.039 in	S0ang	30.000 mDeg	Stf	0.970
Rotor..					
MOH	0.000 in	Nmbp	1	Skew	0.000
RotorOD	7.860 in	Rad1	3.930 in	Gap	0.070 in
LM	0.260 in	BetaM	150.000 eDeg	pupa	0.833
RYoke	0.770 in			RadSH	2.900 in
DHub	7.340 in	wNeck	0.303 in		
MEdge	0.276 in	LM_min	0.260 in		
wMag	2.527 in				
Lstk	8.750 in	Lrotor	8.750 in	Lstator	9.080 in

2 Magnet Data:-----

Magnet	S-L 30MGO				
Br	1.140 T	Hc	1100.000 kA/m	MuRec	1.020
CBr	-0.030 %/DegC	CHc	-0.220 %/DegC	DMag	8400.000 kg/m3
BrT	1.065 T	HcT	567.600 kA/m		
Nuisance	0.000 in	BrTnu	1.065 T	MuRecnu	1.020

3 Control Data:-----

RPM	15000.000 rpm	Vs	146.000 V	Drive	AC Volt
EMFCalc	BLV	delta	46.000 eDeg	Sw_Ctl	Generator

4 Winding Data:-----

Connex	Wye				
WdgType	Custom				
Offset	3	CPP	1.000		
Tph	2.000	PPATHS	4	SPP	1.500
Layers	1.333	CSidesPh	16	Z	48.000
MLT	24.344 in	Lgth0End	10.929 in	Ext	0.000 in
EndFill	0.500	LaxPack	10.488 in	Liner	9.000E-03 in
WireSpec	SFill	SFg	0.400		
NSH	70	WireDia	0.057 in	InsThick	1.150E-03 in
SFg	0.400	SFn	0.585	MaxSFn	0.870
Aslot	0.594 in^2	ASlotLL	0.560 in^2	ACond	0.178 in^2
GPAslot	0.598 in^2	ATstick	0.027 in^2	TopStick	false
TwjWid	0.079 in	TwjLeg	0.138 in	TwjThk	0.015 in
PhsWid	0.079 in	PhsLeg	0.138 in	PhsThk	0.000 in
ATwj	5.315E-03 in^2	APhs	0.000 in^2		
XET	0.725	ETCalc	BDC 6.0	Rext	0.000 ohm
Nse	2.357	X_R	1.000	Ax1	35.000 mDeg
T_Wdg	240.000 DegC	Rph0	8.645E-05 ohm	R_LL	1.729E-04 ohm
T_c	240.000 DegC	Rph	8.645E-05 ohm/ph	TFRho	1.865
Inductances...					
Lph	1.935E-03 mH	Mph	-0.001 mH	XL	1.000

Lg	1.061E-03	mH	LSlot	4.607E-04	mH	Lendt	4.132E-04	mH
Mg	-0.000	mH	MSlot	-0.000	mH	LDiff	1.013E-04	mH
Lsigma	9.752E-04	mH	Msigma	-0.000	mH	XLdiff	1.000	
Lgg	4.604E-03	mH	Mgg	-0.002	mH	PCSlot	1.650	
LL_d	5.066E-03	mH	LL_q	5.052E-03	mH	L_LL	5.059E-03	mH
Lg_0	9.600E-04	mH	Lg_2	2.362E-06	mH	Laa_d	1.938E-03	mH
Ld	2.533E-03	mH	Lq	2.526E-03	mH	Laa_q	1.933E-03	mH
Xd	0.016	ohm/ph	Xq	0.016	ohm/ph	Xsigma	6.847E-03	ohm/ph
XCd	1.000		XCq	1.000		Lext	0.000	mH
Gd	0.217		Gq	0.216		XLendt	1.000	
kw1	0.925		Xm0	0.042	ohm/ph			
ks1	1.000		kp1	1.000		kd1	1.000	
ksg	0.907		fz	1.038		PSSlot	S-Closed	
Saliency	Auto		CalcLdLq	Auto		muPlug	1.000	
i1_Ang	-3877.139	A	i2_Ang	5940.122	A	i3_Ang	-2062.983	A

5 Magnetic Circuit Design:-----

T_Mag	240.000	DegC	T_r	240.000	DegC	XBrT	1.000	
BrT	1.065	T	BgOC	0.794	T	Hca	830.695	kA/m
BgAvOC	0.654	T	PhiG	11.501	mWb	BgA/BgOC	0.824	
Bg1OC	0.964	T	PhiM1	10.792	mWb	Bg1/BgOC	1.214	
BmOC	0.849	T	Bm/BrT	0.797		XBtpk	1.000	
HmOC	-168.458	kA/m	Hm/HcT	-0.297		PC	4.010	
Bst	1.783	T	Bsy	1.713	T	Bry	1.323	T
XTw	0.000		XS YOke	0.000		XRYoke	0.000	
kT	0.120	Nm/A	kE	0.141	Vs/Rad	krpmNL	15.000	krpm
kSat	1.000		XSatn	1.000		CalcSatn	Fixed	
Xks	0.000		ks	0.000		XTTarc	1.000	
EffWst	0.280	in	EffLst	1.056	in	ukCL	0.000	
XBgap	1.000		X_EMF	1.000		k_rpf	1.000	
eLLpk	220.850	V	eTmax	44.934	V	Bslot	-0.000	T
IBk	10971.822	A	Bk	0.000	T	Hk	-830.695	kA/m
ILR	8.444E+05	A	BmLR	-73.117	T	HmLR	-5.79E+04	kA/m
IC180	2.122E+06	A	BmC180	-185.174	T	HmC180	-1.45E+05	kA/m
BHmag	142.993	kJ/m3	Carter	1.008		Xrm	0.500	
Amhp	11.053	in^2	Aghp	11.354	in^2	Rghp	1.948E+05	At/Wb
Pm0	1.384	uWb/At	Xrl	1.000		prl	0.195	
apEnd	1.000		Pend	0.000		Lme	0.260	in
u_LKG	0.000		f_Lkg	0.950		if_Lkg	1.053	
Fringing	ON		XFringe	1.000		XBetaM	1.000	

6 Constant AC Volts static performance [phasor diagram]:-----

OpMode	Generating		Vs	146.000	V	RPM	15000.000	rpm
Tshaft	482.005	lbft	Pshaft	1.027E+06	W	Eff	98.975	%
WCu	4717.794	W	WFe	4696.362	W	WWF	0.000	W
WCan	330.452	W	WMagnet	0.000	W			
WTotal	9744.608	W	TempRise	120.000	DegC	Jrms	5983.803	A/in^2
IWpk	6031.758	A	IWav	3839.912	A	IWrms	4265.097	A
ILpk	6031.758	A	ILav	3839.912	A	ILrms	4265.097	A
IDC_P	6958.953	A	WFeCalc	OC		Pelec	1.016E+06	W
Eq1	88.741	V	Vph1	84.293	V	VLL1	146.000	V
Iph1	4265.097	A	Is	0.000	A			
Iq1	3830.506	A	Id1	1875.705	A	gammaACV	26.090	deg
Vq1	58.555	V	Vd1	60.635	V	delta	46.000	deg
Bg1Load	0.865	T	phi	-19.910	eDeg	PF	0.940	
Bqad	0.000	T	Phida1	2.069	mWb	Phiqa1	4.204	mWb
BmLoad	0.670	T	Bma	-0.178	T	Fda1	-1172.083	At/gap
Tgap_PS	479.278	lbft	TEI_PS	478.827		Trel_PS	0.451	lbft
Tgap	479.645	lbft	Tei	479.194	lbft	Trel	0.451	lbft
Tloop	479.636	lbft						

Vd0 207.572 V Pelec 1.016E+06 W

8 Steady-State Thermal Model:-----

TempCalc	DegCW	FixTMag	IterX	Ambient	120.000	DegC		
DegCW	1.000E-02	degC/W	HTCcyl	10.000	W/m2/C	HTCend	0.000	W/m2/C
TempRise	120.000	DegC	T_c	240.000	DegC	T_r	240.000	DegC
T_f	240.000	DegC	T_y	240.000	DegC	HeatFlux	0.000	kw/m^2
SlotPeri	3.137	in	Liner	9.000E-03	in	ct_Liner	0.200	W/mC
SSArea	27.445	in^2	C_motor	84.069	kJ/C	ThRSlot	1.793E-03	C/W
FSArea	883.997	in^2						

9 Miscellaneous:-----

Weights...

wt_Cu	33.437	lb	wt_Fe	111.158	lb	wt_Mag	14.225	lb
wt_Tot	158.821	lb	wt_Shaft	142.800	lb	wt_Frame	39.567	lb
wt_FeS	73.577	lb	wt_FeR	37.581	lb	wt_RSS	195.059	lb
Inertia components...								
RotJ	0.356	kg-m2	RotJSS	0.358	kg-m2	RotJSh	0.176	kg-m2
RotJFe	0.120	kg-m2	RotJMag	0.060	kg-m2	LShaft	20.000	in
sigma	6.778	psi						
Wf0	0.000	W	RPM0	1000.000	rpm	NWFT	1.000	
Fringing	ON		XFringe	1.000		NHx	21	
CanStyle	Rotor		SCanThk	0.020	in	SCanSecs	1	
pc_Scan	2.500	%	pc_Mag	0.000	%	pc_Sh	0.000	%
Ecc	0.000		UMPavg	-1.88E-14	lb	UMPmax	4.769E-13	lb
TRFrms	213.228	lb	TRFavg	192.385	lb	TRFmax	261.647	lb
CForce	43182.709	lb				LamThk	6.000E-03	in
NLams	1415		pcLam	3.000	%	RFei	1.000E+06	

10 Core loss analysis:-----

WFeCalc	OC	LossFE	Mech	XFe	1.000			
DFekgS	7480.246	kg/m^3	St.Steel	Hiperco 50 (7mil)				
DFekgR	7480.246	kg/m^3	Ro.Steel	Hiperco 50 (7mil)				
DFekgSh	7480.246	kg/m^3	Sh.Steel	Hiperco 50 (7mil)				
wt_Teeth	30.181	lb	wt_Yoke	43.397	lb	wt_Troot	6.358	lb
Specific core losses...								
cFe_E60	0.053	W/lb	cFe_H60	1.254	W/lb	cFe_60	1.307	W/lb
cFe_E_F	14.643	W/lb	cFe_H_F	20.900	W/lb	cFe_F	35.544	W/lb
cFe_T_E	47.300	W/lb	cFe_T_H	28.044	W/lb	cFe_T	75.343	W/lb
cFe_Y_E	18.582	W/lb	cFe_Y_H	26.201	W/lb	cFe_Y	44.782	W/lb
Core loss analysis...								
WFe_T_E	1728.267	W	WFe_T_H	1024.681	W	WFe_T	2752.947	W
WFe_Y_E	806.390	W	WFe_Y_H	1137.025	W	WFe_Y	1943.415	W

End of Design sheet-----