

Wet Rotor Cooling

Description

This document gives a brief description of how to set up a Motor-CAD model for a wet rotor machine.

Wet rotor cooling is where a fluid is passed down the airgap of the machine. The fluid also passed over the shaft and end-winding surfaces in the endcap regions of the machine. This form of cooling is often used for integrated pumps where leakage from the pump is used to cool the motor.

Machine Geometry

For this example the standard machine will be used as shown below.

The screenshot displays the Motor-CAD v5.3.2.9 software interface. The main window shows a cross-sectional view of a motor with a cyan shaft, a green airgap, a red stator with yellow teeth, and a blue housing with cooling fins. The software title bar indicates 'Motor-CAD v5.3.2.9 (No File)'. The menu bar includes 'File', 'Options', 'Defaults', 'Editors', 'View', 'Results', 'Tools', and 'Help'. The toolbar contains various icons for file operations and simulation. The 'Motor Type' is set to 'BPM' and the 'Title' is 'Default Motor'. The 'Radial Cross-Section' tab is active. The 'Housing' is set to 'Axial Fins (Sv)' and 'Mounting' is 'Flange'. The 'Slot Type' is 'Parallel Tooth' and 'Rotor Ducts' is 'None'. The 'BPM Rotor' is set to 'Surface Radial'. A table on the left lists the following parameters:

Stator Dims.	Data	Rotor Dims.	Data
Slot Number	18	Pole Number	6
Housing Dia	140	Magnet Thickness	4
Stator Lam Dia	130	Magnet Arc [ED]	140
Stator Bore	80	Airgap	1
Tooth Width	7	Banding Thickness	0
Slot Depth	18	Shaft Dia	25
Slot Corner Radius	0	Shaft Hole Diameter	0
Slot Opening	3		
Tooth Tip Depth	1		
Tooth Tip Angle	30		
Sleeve Thickness	0		
Fin Extension	10		
Fin Thickness	2		
Fin Pitch/Thick	5		
Fin Pitch [Calc]	10		
Corner Cutout [%]	40		
Corner Cutout Add	0		
Plate Height	350		
Plate Width	350		
Stator Ducts	0		

At the bottom of the window, there is a 'Redraw' button and checkboxes for 'Draw plate' and 'Draw base'. The status bar at the bottom shows 'Length (-54.12,81.48) mm 17 July 2009 www.motor-design.com'.

Setting the machine losses

The losses of the machine are defined in the losses page as shown below. The default losses are used in this example. There are different loss models allowing for the losses to vary with speed, temperature and load.

Motor-CAD v5.3.2.9 (C:\workspace\Motor-CAD tutorials\TVent.mot)*

File Options Defaults Editors View Results Tools Help

Motor Type: BPM Title: Default Motor

Radial Cross-Section Axial Cross-Section Winding Editor Input Data Schematic Node Temperatures Output Data Transient Graph Circuit Editor Sensitivity Scripting

Cooling Options Losses Materials & Weights Interface Gaps Radiation Natural Convection Through Ventilation End Space Transient Settings Material Properties

Loss Variation with Speed:

$P[\text{speed}] = P[\text{input}] \times \left[\frac{\text{Shaft Speed}}{\text{Speed}[\text{REF}]} \right]^{\text{coef}[\text{A}]}$

Speed Dependent Losses
Shaft Speed [rpm] 3000

Single value of Speed[REF] [rpm] 3000

Component	P[input]	Speed[REF]	coef[A]	W/kg	P[speed]
Units	Watts	rpm		W/kg	Watts
Loss [Stator Copper]	120	3000	0	87.29	120
Loss [Stator Back Iron]	30	3000	1.5	16.29	30
Loss [Stator Tooth]	40	3000	1.5	24.44	40
Loss [Magnet]	0	3000	0	0	0
Loss [Rotor Back Iron]	0	3000	0	0	0
Loss [Friction - F Bearing]	2	3000	1	0	2
Loss [Friction - R Bearing]	2	3000	1	0	2
Loss [Windage]	10	3000	3	0	10
Loss [Windage] [Ext Fan]	0	3000	3	0	0
Power Injected [Endcap Front]	0	3000	0	0	0
Power Injected [Endcap Rear]	0	3000	0	0	0
Power Injected [Feet]	0	3000	0	0	0
Power Injected [Shaft Active]	0	3000	0	0	0
Power Injected [Shaft Front]	0	3000	0	0	0
Power Injected [Shaft Rear]	0	3000	0	0	0
Power Injected [EWdg Front]	0	3000	0	0	0
Power Injected [EWdg Rear]	0	3000	0	0	0
Power Injected [Plate]	0	3000	0	0	0
Power Injected [Wdg Outer]	0	3000	0	0	0
Power Injected [ESpace Front]	0	3000	0	0	0
Power Injected [ESpace Rear]	0	3000	0	0	0

Stall Copper Loss Distribution:

Equal (Ia = Ib = Ic) Sine (Ia/2 = Ib = Ic)

6-step (Ia = Ib, Ic = 0)

Winding Temp Variation with Proximity Loss Distribution:

Percentage Winding Temperature Increase (at Proximity RPM): 0

Proximity RPM: 1E4

Copper Loss Variation with Temperature

Copper Losses Vary with Temperature
Winding Temperature at which Pcu Input: 20

Loss Variation with Temperature & Load:

Losses Vary with Temperature & Load

Constant Torque or Constant Current

Constant Torque Constant Current

Winding Temperature - Tw(i/p): 120

Magnet Temperature - Tm(i/p): 80

Shaft Torque [Nm] (@Pcu defined): 15

Motor Current [Ams] (@Pcu defined): 8.114

Torque Constant [Nm/A]: 1.849

Torque & Current Multiplier: 1

Rph @Tw(i/p): 0.45

Magnet Temperature Coefficient Br: -0.06667

Iron Loss Flux To Power Ratio: 1.5

Phases: 3

Losses Notes:

Check Data

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Setting the machine cooling

The machine cooling is setup as shown below.

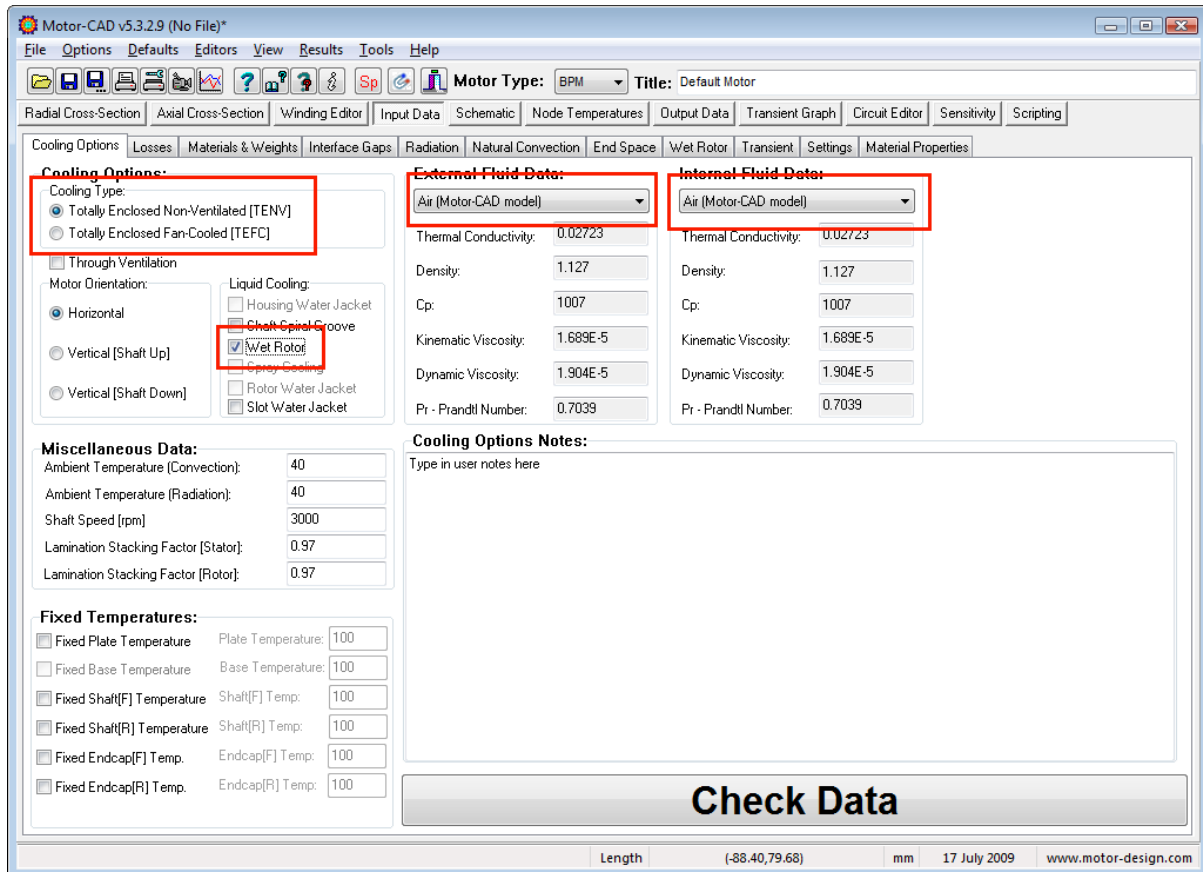
The wet rotor option must be selected.

The cooling type on the exterior of the housing is specified using the Cooling Type option:

- Totally Enclosed Non-Ventilated = only natural convection and radiation from outside of machine.
- Totally Enclosed Fan-Cooled = air/ fluid is blown over outside of machine.

The External fluid is the fluid on the outside of the machine. The internal fluid is the fluid blown through the machine.

The fluids and their properties can be created and edited in the fluid data base (Input Data->Material Properties->Fluids).



The Wet rotor settings are defined by setting the options shown below. In this case the default model settings are used and the fluid is changed to water.

Fluid Data:
 Inlet Temperature: 40
 Fluid Volume Flow Rate: 0.3593

Fluid Properties:
 Water

Fluid Velocity in Airgap:
 h[Wet Rotor] Velocity Selection:
 h based on Axial Fluid Velocity
 h based on Effective Fluid Velocity

Shaft Speed [rpm]: 3000
 Axial Velocity Multiplier: 1
 Axial Velocity: 0.02418
 Peripheral Velocity: 6.126
 Effective Velocity: 6.126

Wet Rotor Flow Path:
 Front Inlet
 Rear Inlet
 Central Inlet
 Central Outlet

Wet Rotor Inlet/Outlet Position:
 Front: Axial Radial
 Rear: Axial Radial

Fluid Flow:
 Slot Wedge Fluid Flow
 Coil Divider Fluid Flow
 Slot Wedge Flow Adjustment: 1
 Coil Divider Flow Adjustment: 1
 Gap Flow Adjustment: 1
 Flow Rate: 0
 Flow Rate: 0
 Flow Rate: 0.3593

Component	Input h?	Convection Correlation	h[input] or h[adjust]	Local Velocity Multiplier	Local Fluid Velocity	Re Number	%Re(crit)	h	Notes
Units			W/m2/C	pu	m/s		%	W/m2/C	
Stator Bore	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	6.126	1.859E04	664	35893	
Rotor Surface	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	6.126	1.859E04	664	35893	
EWdg Bore [F]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
Shaft [F]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
EWdg Bore [R]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
Shaft [R]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	

Check Data

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The flow velocities and heat transfer coefficients are calculated by Motor-CAD as shown below.

The screenshot displays the Motor-CAD v5.3.2.9 software interface. The 'Input Data' tab is active, showing fluid properties for water and calculated fluid velocities in the airgap. A table below the settings provides detailed data for various components, with a red box highlighting the heat transfer coefficient (h) and related parameters for the Stator Bore, Rotor Surface, and various airgap regions.

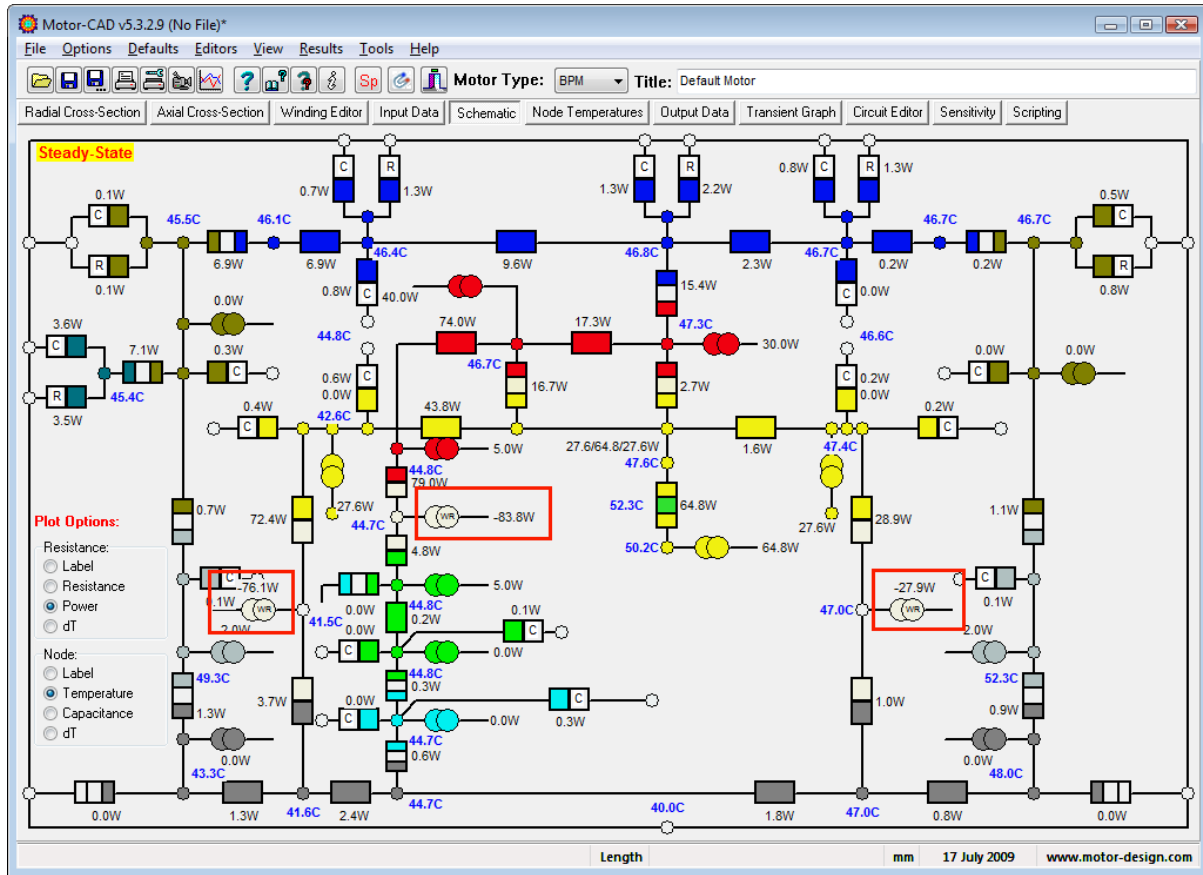
Component	Input h?	Convection Correlation	h[input] or h[adjust]	Local Velocity Multiplier	Local Fluid Velocity	Re Number	%Re(crit)	h	Notes
Units			W/m ² /C	pu	m/s		%	W/m ² /C	
Stator Bore	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	6.126	1.859E04	664	35893	
Rotor Surface	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	6.126	1.859E04	664	35893	
EWdg Bore [F]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
Shaft [F]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
EWdg Bore [R]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	
Shaft [R]	<input type="checkbox"/>	Channel Correlation [Turbulent]	1	1	1.963	1.78E05	6356	8280.8	

Check Data

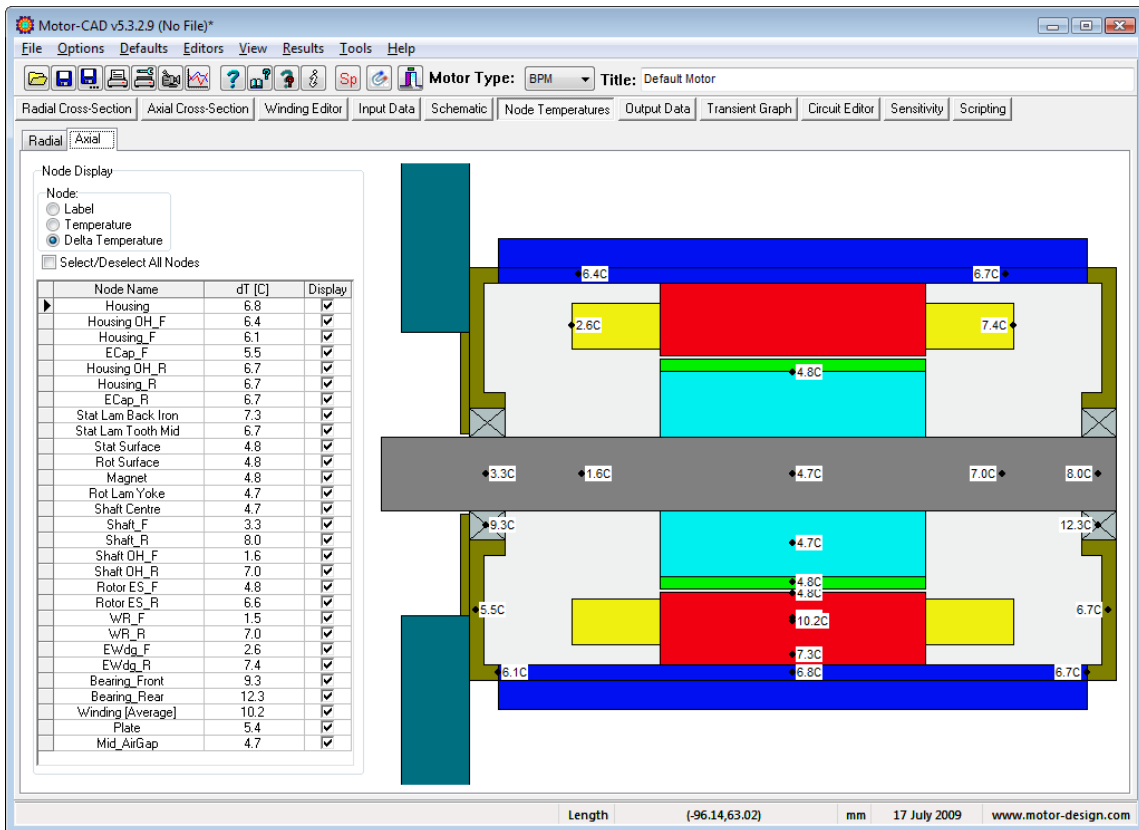
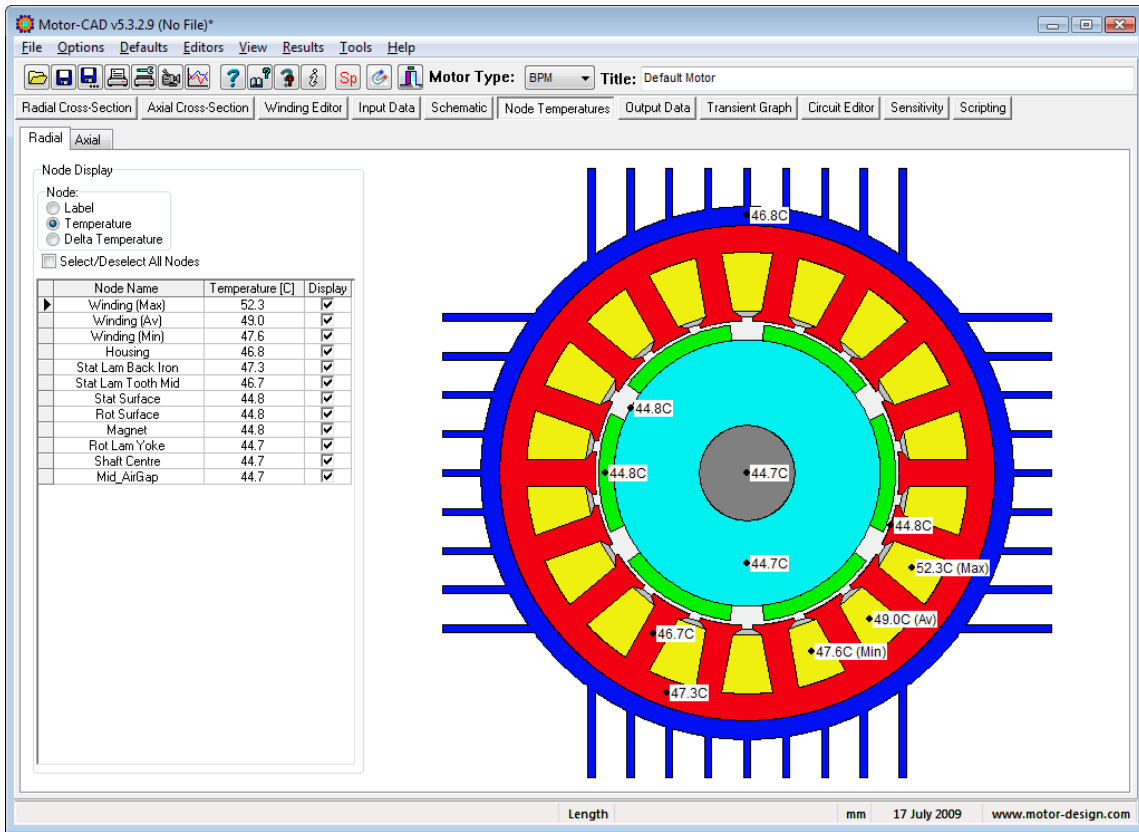
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Viewing the results

The power removed from the machine by the wet rotor fluid from airgap, end windings and shaft is shown in the steady state schematic.



The node temperatures can also be viewed on the radial and axial cross sections as shown below.



The wet rotor fluid dissipation values are shown in the output data sheet as shown below.

Variable	Value	Units	Variable	Value	Units
Loss [Stator Copper]	120	Watts	Loss [Stator Copper] @Tm(i/p)	162.7	Watts
Loss [Stator Back Iron]	30	Watts	Loss [Stator Tooth] @Tm(i/p)	37.59	Watts
Loss [Stator Tooth]	40	Watts	Loss [Magnet] @Tm(i/p)	0	Watts
Loss [Magnet]	0	Watts	Loss [Rotor Back Iron] @Tm(i/p)	0	Watts
Loss [Rotor Back Iron]	0	Watts	Loss [Airgap Banding] @Tm(i/p)	0	Watts
Loss [Airgap Banding]	0	Watts	Loss [Winding Sleeve] @Tm(i/p)	0	Watts
Loss [Winding Sleeve]	0	Watts	Winding Temperature - Tm(i/p)	120	C
Loss [Winding]	10	Watts	T [Active Winding Average]	50.19	C
Loss [Winding] [Ext Fan]	0	Watts	T [End Winding Average]	47.61	C
Loss [Friction - F Bearing]	2	Watts	T [Winding Average]	48.99	C
Loss [Friction - R Bearing]	2	Watts	Magnet Temperature - Tm(i/p)	80	C
Loss [Copper Layer = 1]	14.5	Watts	T [Magnet]	44.75	C
Loss [Copper Layer = 2]	13.89	Watts	Shaft Torque [1pu]	15	Nm
Loss [Copper Layer = 3]	13.27	Watts	Shaft Torque [Required]	15	Nm
Loss [Copper Layer = 4]	12.64	Watts	Torque Constant	1.849	
Loss [Copper Layer = 5]	12.02	Watts	Torque Current Multiplier	1	
Loss [Copper Layer = 6]	11.39	Watts	Rph @Tm(i/p)	0.45	ohms
Loss [Copper Layer = 7]	10.76	Watts	Rph	0.3598	ohms
Loss [Copper Layer = 8]	10.12	Watts	Rph 20C	0.323	ohms
Loss [Copper Layer = 9]	8.926	Watts	RMS Torque	31.85	
Loss [Copper Layer = 10]	6.547	Watts	RMS Torque [pu]	2.123	
Loss [Copper Layer = 11]	4.165	Watts	Proximity Winding Resistance Multiplier	1	
Loss [Copper Layer = 12]	1.779	Watts	Flux Ratio	1.042	
Loss [Total]	204	Watts	Mechanical Loss @Tm(i/p)	79.78	Watts
Dissipation [Front EWdg Bore]	72.36	Watts	Mechanical Loss	84	Watts
Dissipation [Shaft Front]	3.733	Watts	Torque Loss	0.2674	Nm
Fluid Dissipation [E Space F]	76.09	Watts	EM Torque @Tm(i/p)	15.25	Nm
Dissipation [Stator Bore]	78.98	Watts	EM Torque	15.27	Nm
Dissipation [Rotor Surface]	4.84	Watts	Iph [1pu]	8.114	Amps
Dissipation [Rear EWdg Bore]	28.87	Watts	Iph @Tm(i/p) & Tm(i/p)	10.98	Amps
Dissipation [Shaft Rear]	-0.9556	Watts	Iph	10.54	Amps
Fluid Dissipation [E Space F]	76.09	Watts			
Fluid Dissipation [Airgap]	83.82	Watts			
Fluid Dissipation [E Space R]	27.92	Watts			
Dissipation - Active Housing [Con]	1.238	Watts			
Dissipation - Active Housing [Rad]	2.196	Watts			
Dissipation - Front Housing [Con]	0.7294	Watts			
Dissipation - Front Housing [Rad]	1.261	Watts			
Dissipation - Rear Housing [Con]	0.778	Watts			
Dissipation - Rear Housing [Rad]	1.323	Watts			
Dissipation - Front Endcap [Con]	0.08067	Watts			
Dissipation - Front Endcap [Rad]	0.1379	Watts			
Dissipation - Rear Endcap [Con]	0.5075	Watts			
Dissipation - Rear Endcap [Rad]	0.7586	Watts			
Dissipation - Plate [Con]	3.624	Watts			
Dissipation - Plate [Rad]	3.479	Watts			

Transient Analysis

Transient analysis can also be performed on this model. Full details of the transient analysis options and method of calculation are given in the transient analysis tutorial.

