GOT-It
Optimizing PM Machines

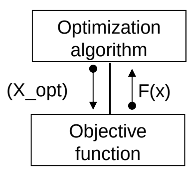
Philippe Wendling
philippe.wendling@magsoft-flux.com

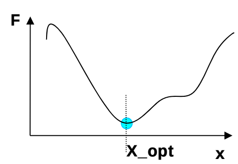
Create, Design, Engineer!

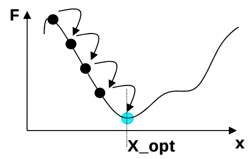
www.magsoft-flux.com
www.cedrat.com

Introduction: The Optimization

- Find the best value of input parameters that maximizes or minimizes an objective function taking into account constraints
- Use optimization algorithms that propose search strategies to find the optimum, based on evaluations of the objective function.







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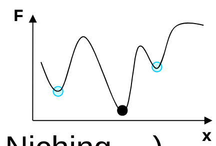
General optimization strategies…

Deterministic algorithms (SQP, Conjugate gradients,…)

- Fast
- Based on local function variations
- Efficient to find local optimum
- Need gradients of the functions



Stochastic algorithms (Genetic algorithms, Niching,…)

- Time-consuming
- Based on wide number of trials
- Efficient to find the global optimum
- Do not need gradients of the functions

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Based on numerical models…

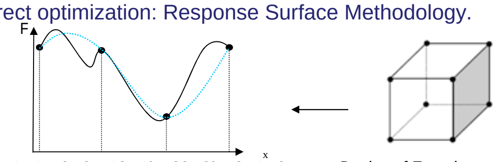
The time to evaluate the objective functions must be minimal:

- Each Finite Element evaluation is costly,
- They must be performed many times.

A good approach is based on Design Of Experiment.

Two strategies:

- Reduce the number of input parameters: Screening,
- Use indirect optimization: Response Surface Methodology.



$F'(x)= a0 + a1.x1 + a2.x2 + a12.x1^2 + a22.x2^2 + a3.x1.x2$ *Design of Experiment tables*

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Strategy to reduce the size

Screening: detect the most influent parameters:

- Can sort a large number of parameters,
- Reduce needed set of calculations.

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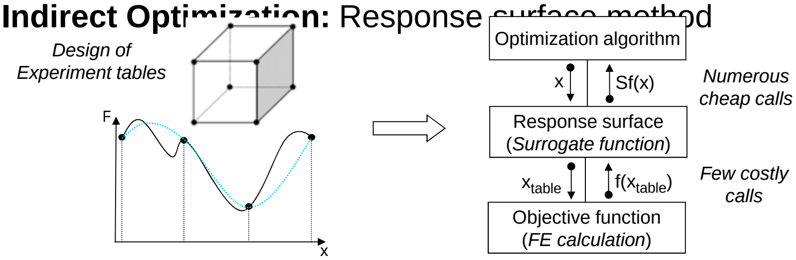
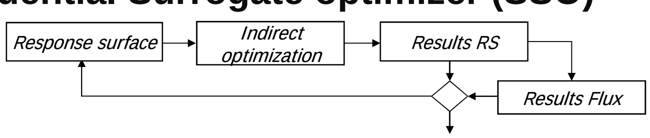
Strategy to reduce computation time

Indirect Optimization: Response surface method



Build surrogate function ***Response surface Method***

Sequential Surrogate optimizer (SSO)



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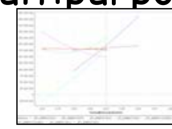
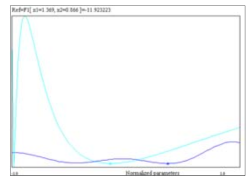
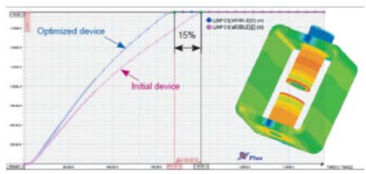
An Industrial and Multipurpose Tool

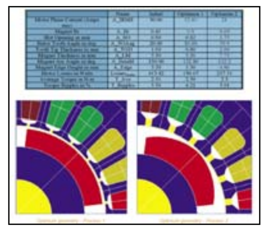


A wide range of applications:

- Minimize losses in a machine,
- Minimize torque ripples,
- Minimize time-response of an actuator,
- Reduce electric field along a path,
- Maximize efficiency of electromechanical conversion.







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GOT-It Features...

Continuous and/or discrete parameters,
Single or multi-objective functions,
Constrained or unconstrained optimization,
Analytical functions or functions derived from numerical models,
Design Of Experiments (DOE),
Response surfaces (polynomial, RBF, kriging, Space Mapping).
Direct or indirect (SRM) optimization techniques.
Deterministic (CG, BFGS) or stochastic (GA, Niching, PSO) algorithms,
Post-processing (curves, surfaces, Pareto frontiers, sensitivity analysis, automatic report).

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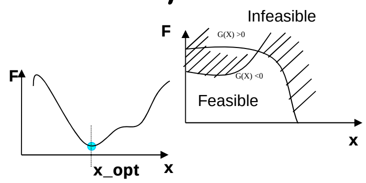
Basic Operation



Define the optimization problem

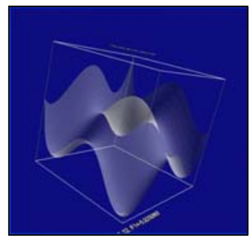
- Objective function (mono or multi-objective)
- Constraints
- Variations of input parameters

Choose an optimization algorithm and run it

- Deterministic or stochastic
- Can be chosen automatically by GOT-It

Post-process the results

- Draw curves
- Create automatic report (html format)



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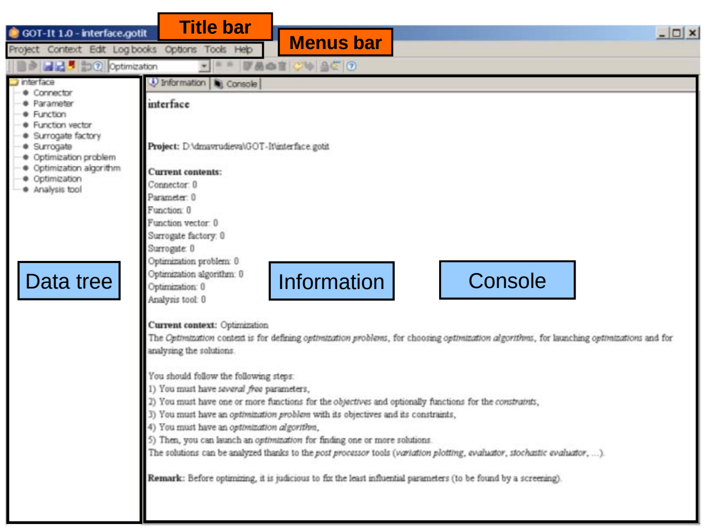
GOT-It interface



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GOT-It contexts

- The selected context determines the level of use

Context	***Allows mainly…***
Parametric Parametric enhanced	Handling parametric studies
Screening	Finding the most influent parameters
Model reduction	Building response surfaces
Optimization Optimization enhanced	Defining optimization problems, choosing optimization algorithms, launching optimizations and analyzing the optimum solutions
Expert	using expert functionalities

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GOT-It entities

The selected context also determines the entities used

Parameter
Function
Parametric
Function vector
Parametric enhanced
Surrogate factory
Surrogate
Screening
Model reduction
Optimization problem
Optimization algorithm
Optimization
Optimization
Optimization enhanced
Optimization problem factory
Stochastic operator
Expert

Connector and Analysis tool are available in all contexts

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GOT-It analysis tools…

Evaluator : $F(x_1,x_2,\ldots,x_n)$ evaluation for reference values of x_n

Curve plotting : variation curve of F(x)

Surface plotting : variation surface of $F(x_1,x_2)$

Isoval plotting : parametric isovalues

Screening analyzer : sensitivity analysis of $F(x_1,x_2,\ldots,x_n)$

Variation plotting : Function variations around the optimum

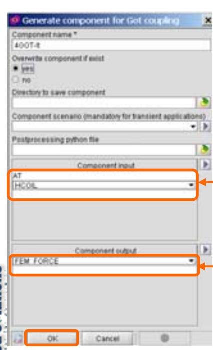
Stochastic evaluator : robustness analysis

Pareto frontier : Pareto frontier in multi-objective optimizations

GOT-It - Flux coupling set up

1) Export coupling component from Flux project

Solving | Generate component for Got coupling

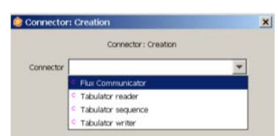


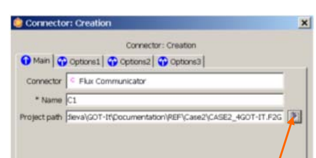
Input parameters:
Geometric parameters
Parameters I/O (scenario)

Output functions:
Parameters I/O (formula)
Sensors

- ✓ *FluxFileForGOT-It.**F2G.FLU***
- ✓ *LinkComponent.**F2G***

2) Create Flux communicator in GOT-It project





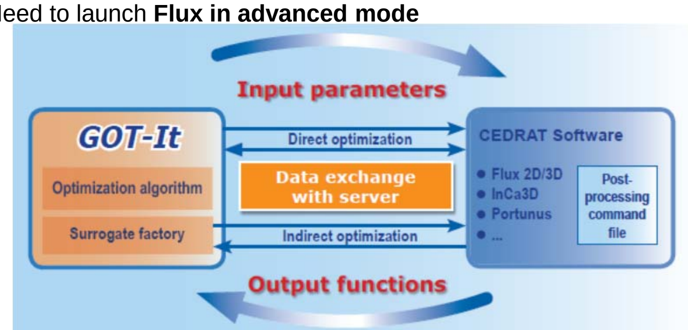
Select (**.F2G**) file exported from Flux

Coupling technology

GOT-It drives optimization based on CEDRAT tools simulations

Available in Flux v10.4.1 and subsequent versions

- 2D, 3D and Skew applications (according to the Flux license)
- Need to launch **Flux in advanced mode**



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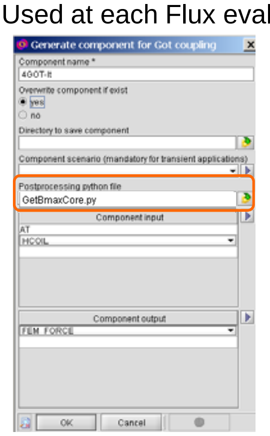
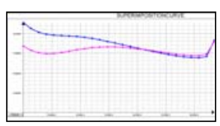
Post processing command files

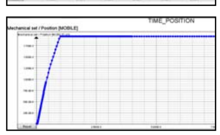
Specified in the coupling component for GOT-It

Used at each Flux evaluation

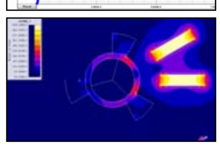




- ✓ To get the min, max, mean value of a 2D curve



- ✓ To get the time response



- ✓ To compute losses, performances, cogging torque,…

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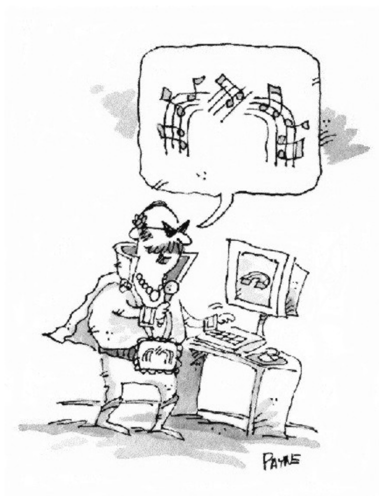
See how it works!



17

Example 1: Minimize Core Losses and Cogging Torque

Industrial Application

- Motor pump
- Water cooled

General Characteritics

- Constant speed operation at 2000 rpm
- 0.7 hp
- 4 poles
- 24 slots
- 3 Phase Y connected winding

Drive Information

- Sine
- 48 Volts
- 50 Amps max

18

Brushless PM Motor Dimensions/Materials

Motor Key Dimensions

	Value	Unit
Stator OD	96.0	mm
Rotor OD	50.0	mm
Gap	0.5	mm
Stack Length	50.0	mm
Magnet Thickness	5.5	mm

Motor Materials

- Stator laminations: M19 24 Gauge equivalent
- Rotor hub: 430F
- Magnet: Ferrite grade

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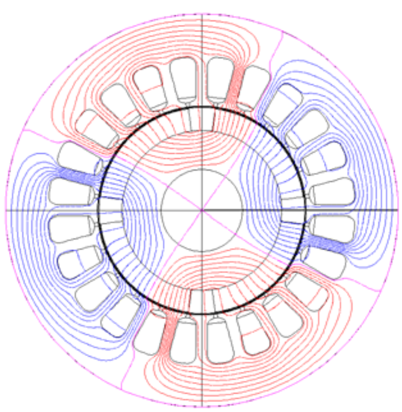
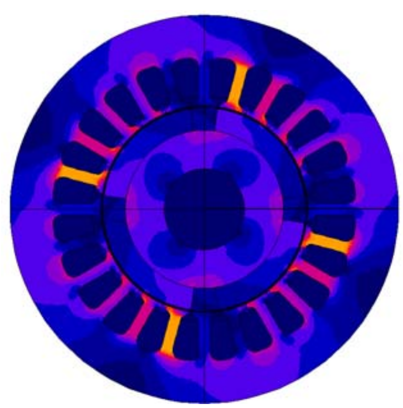
Motor Performances

Motor Magnetic Flux and Saturation





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Motor Performances

Performances

- 55% Efficiency
- 2.54 N.m shaft torque at 2000 rpm
- 0.7 hp
- Torque ripples ~ 6%

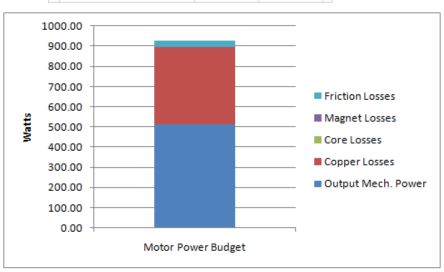
Losses: 420 Watts

- Stator winding copper losses: 381 Watts
- Stator core losses (estimated): 2.42 Watts
- Bearing friction losses: 30 Watts

Motor Power Budget Analysis

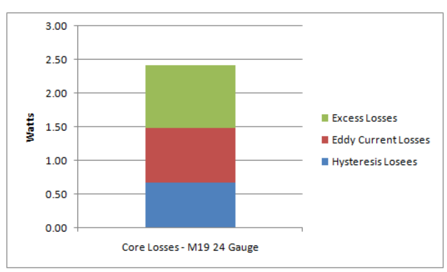
Power Budget

Output Mech. Power	513.13	Watts
Copper Losses	381.00	Watts
Core Losses	2.42	Watts
Friction Losses	30.00	Watts
Magnet Losses	0.36	Watts
Total Power	926.91	Watts
Eff	55.36	%



Core Loss Components

Hysteresis Losees	0.67	Watts
Eddy Current Losses	0.81	Watts
Excess Losses	0.94	Watts
Total Core Losses	2.42	Watts



Losses Minimization and Torque Ripples Reduction

Objective

- Increase motor efficiency by reducing the motor losses
- Reduce torque ripples

Strategy: 2 approaches

- 2 sequential optimization problems with constraints
  - Losses minimization
  - Torque ripples minimization
- Single step multi-constraints losses and torque ripples minimization
  - Objective: minimum losses
  - Constraint: torque ripples below 4.5%

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Losses Minimization and Torque Ripples Reduction

The Parameters

Geometric

- Magnet arc A_BetaM
- Magnet edge A_Edge
- Magnet thickness A_LM
- Stator slot opening A_SO
- Stator slot angle A_SOAng
- Stator tip thickness A_TGD

Physics

- Motor drive rms current Airms
- Magnet remanent flux density Abr

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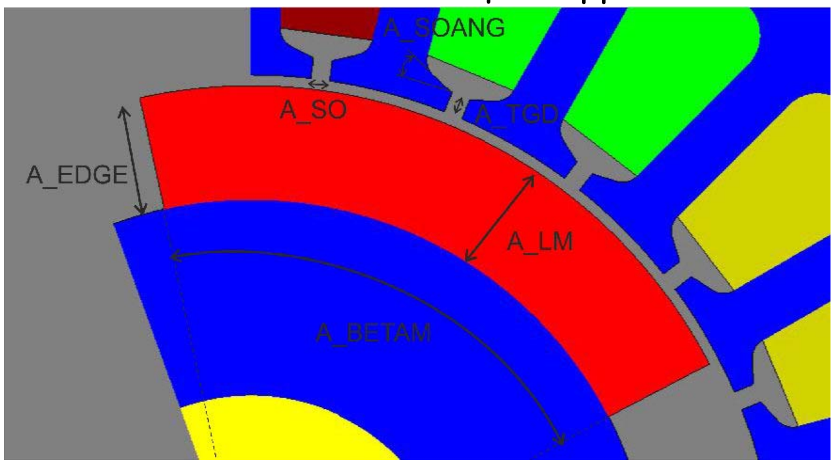
Losses Minimization and Torque Ripples Reduction



Method 1 - Screening and 2 Steps Optimization

- Screening and Identification
- Separation of losses minimization and torque ripples reduction
  - Significant stator winding copper losses
  - Motor magnetics not saturated
- Losses main contributor and key parameter
  - Stator winding copper losses
  - Motor drive current
  - Constraint on minimum torque requirement => stronger magnet
- Torque ripples reduction
  - Shaping of stator tooth geometry
  - Shaping of magnet
  - Constraint on minimum torque requirement

Screening and 2 Steps Optimization
Step 1 Losses Minimization

Optimization Algorithm

- Sequential quadratic programming

Results

- Winding losses are reduced from 382 Watts to 96 Watts
- Current is reduced from 30 Amps to 15.4 Amps
- Magnet Br is increased from 0.41 T to 0.8 T
- 3 SQP iterations

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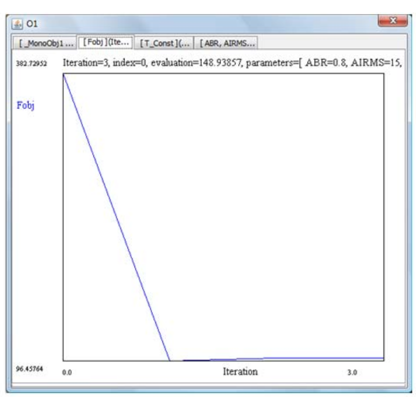
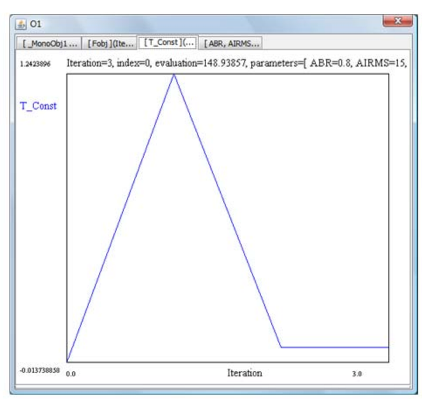
Screening and 2 Steps Optimization
Step 1 Losses Minimization

Results: motor losses objective function and torque constrainst





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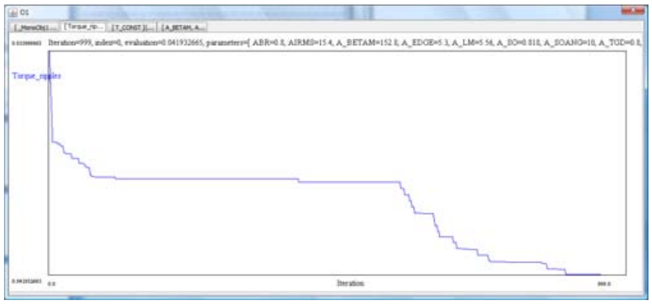
Screening and 2 Steps Optimization
Step 2 Torque Ripples Minimization

Optimization Algorithm

- Genetic algorithm

Results

- Torque ripples are decreased from 5.6% to 4.2%



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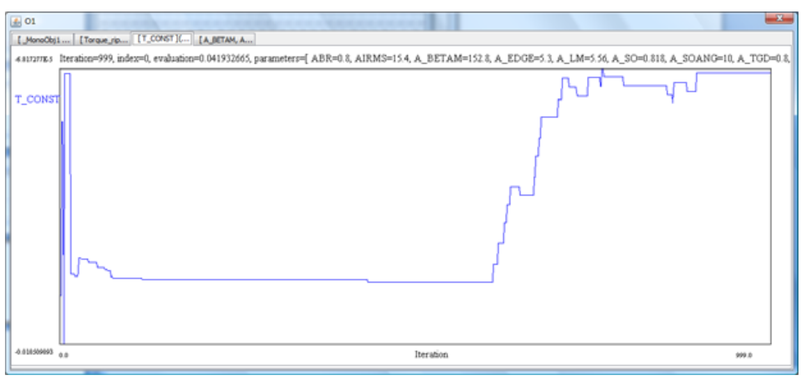
Screening and 2 Steps Optimization
Step 2 Torque Ripples Minimization

Results: motor torque constraint



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Method 2 - Losses Minimization with Torque Constraints

Objective Function

- Motor losses

Constraint

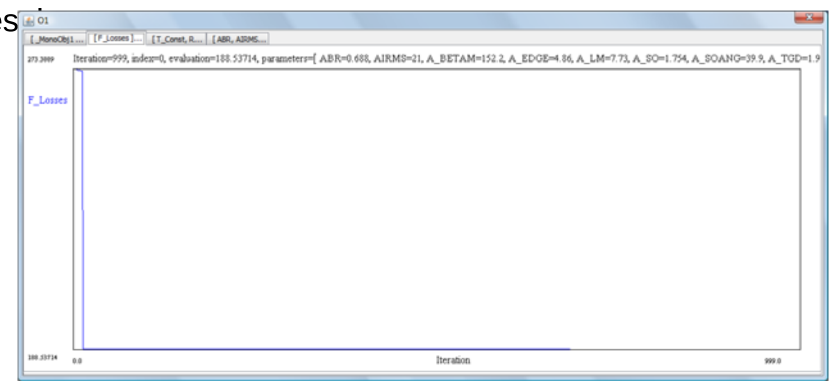
- Minimum torque requirement
- Torque ripples less than 4.5%

Results

- Achieved motor losses: 217.31 Watts
- Resulting torque ripples 3%

Losses Minimization with Torque Constraints

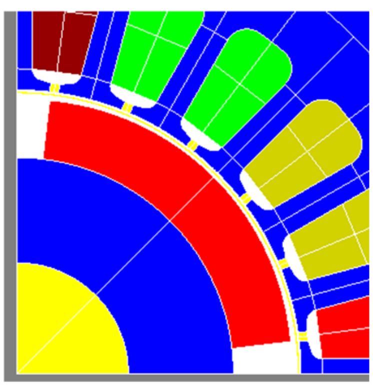
Res

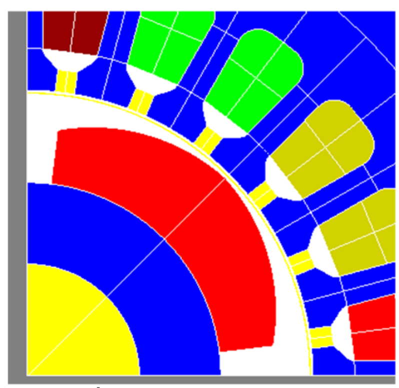


Results Summary

	Name	Initial	Optimum 1	Optimum 2
Motor Phase Current (Amps rms)	A_IRMS	30.00	15.40	21
Magnet Br	A_Br	0.41	0.8	0.69
Slot Opening in mm	A_SO	0.90	0.82	1.75
Stator Tooth Angle in deg.	A_SOAng	20.00	10.00	39.9
Tooth Tip Thickness in mm	A_TGD	1.00	0.80	2.00
Magnet Thickness in mm	A_LM	5.50	5.56	7.73
Magnet Arc Angle in deg.	A_BetaM	150.00	152.80	152.2
Magnet Edge Height in mm	A_Edge	5.50	5.30	4.86
Motor Losses in Watts	$Losses_{motor}$	413.42	130.67	217.31
Average Torque in N.m	T_Ave	2.51	2.50	2.5
Torque Ripples in %	T_Ripples	5.56	4.21	3.01

Optimization Results


Optimum Geometry – Process 1

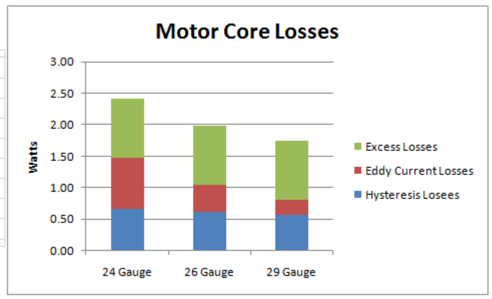

Optimum Geometry – Process 2

Impact of Lamination Changes

M19 Equivalent 24, 26 and 29 Gauge

- Higher gauge, thinner lamination
- Less losses but not significant
- Increase manufacturing cost with more laminations
- More expensive

M19	24 Gauge	26 Gauge	29 Gauge	
Thickness	0.64	0.47	0.36	mm
Number of Lams	79	106	140	
Hysteresis Losees	0.67	0.61	0.56	Watts
Eddy Current Losses	0.81	0.44	0.25	Watts
Excess Losses	0.94	0.94	0.93	Watts
Total Core Losses	*2.42*	*1.99*	*1.74*	Watts
Delta Losses	NA	-0.43	-0.68	Watts
Delta	NA	-17.70	-28.04	%



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Example 2: Minimize Magnet Weight

Motor (for hybrid electrical vehicule)

Ratings

- Max bus voltage : 500 V
- Peak torque : 400 Nm
- Max speed : 6000 rpm
- Peak power rating : 50 kW at 1200-1500 rpm

Motor characteristics

- 48 stator slots
- 3 phases wye connected
- 8 poles
- NdFeB magnet
- Lamination type M270-35A
- Outer diameter : 242 mm
- Stack length : 75 mm

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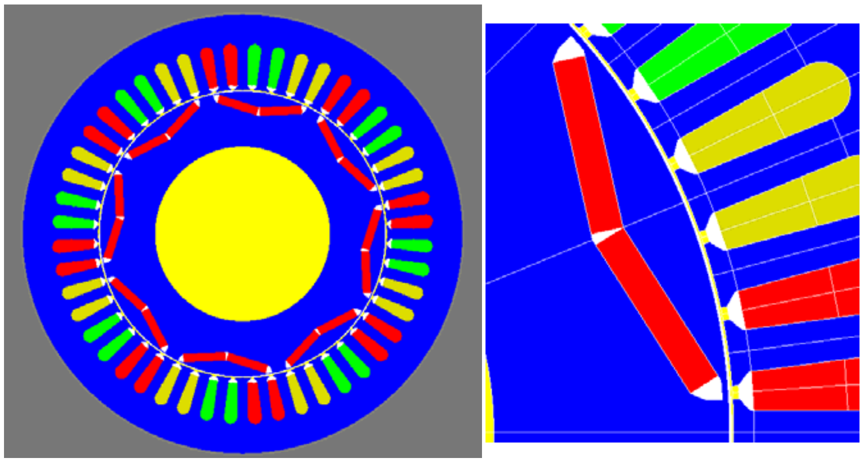
The machine: the real design



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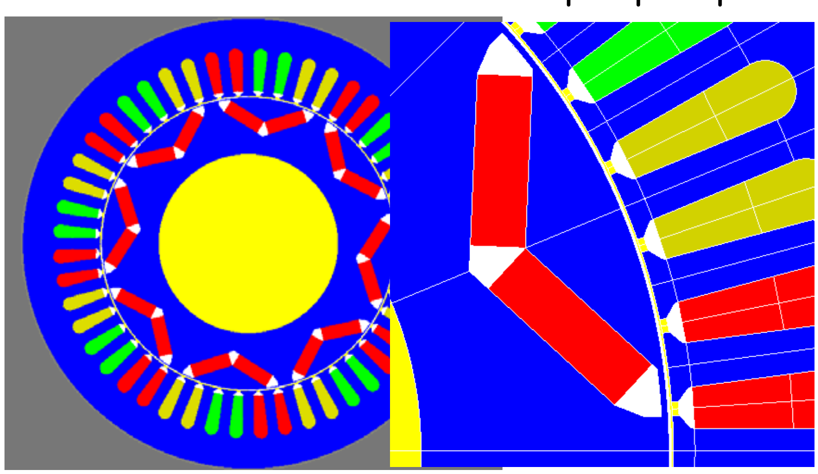
Our starting design: larger magnets, deeper pole piece



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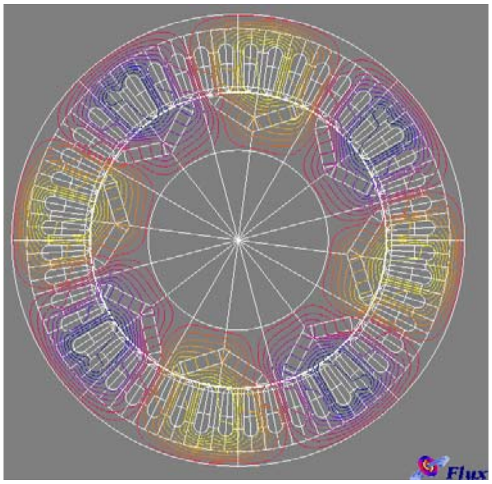
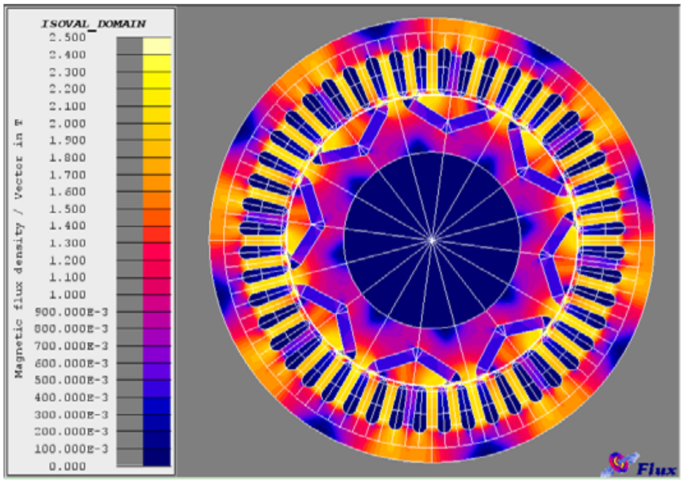
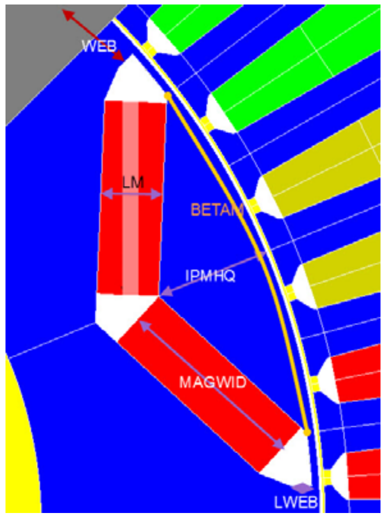
Starting Design – Flux Lines



Starting Design – Flux Density



Screening: 6 Geometric Parameters



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41

Screening: 6+2 Parameters

[Parameter]: Edition

[Parameter]: Edition

Main | Options | Status

	BETAM	BR	GAMMA	IPMHQ	LM	LWEB	MAGWID	WEB
Parameter	P Con...	P Con...	P Con...	P Con...	P Con...	P Con...	P Con...	P Con...
* Name	BETAM	BR	GAMMA	IPMHQ	LM	LWEB	MAGWID	WEB
* Value	150	1.15	45	15	9	2.75	50	10
* Interval: Minimum value	100	1.05	0	6	2	0.5	20	2
* Interval: Maximum value	155	1.2	85	20	12	8	60	12
Fixed	☐	☐	☐	☐	☐	☐	☐	☐

Physics Parameters

Validate | Restore | Close

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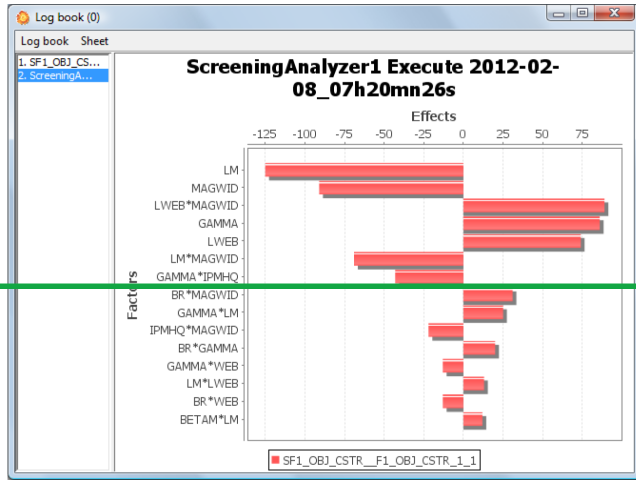
42

Box 64 Screening 8 Parameters



adapted solutions

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43

Screening Results Box 64

Given the range of exploration set for each parameter:

- As expected LM and MAGWID are the key parameters – we are trying to minimize weight,
- Br has little impact – within the range of exploration
- BETAM seems to have limited impact

The screening is run with only 5 parameters

Solutions evaluated during screening are the basis for the final optimisation

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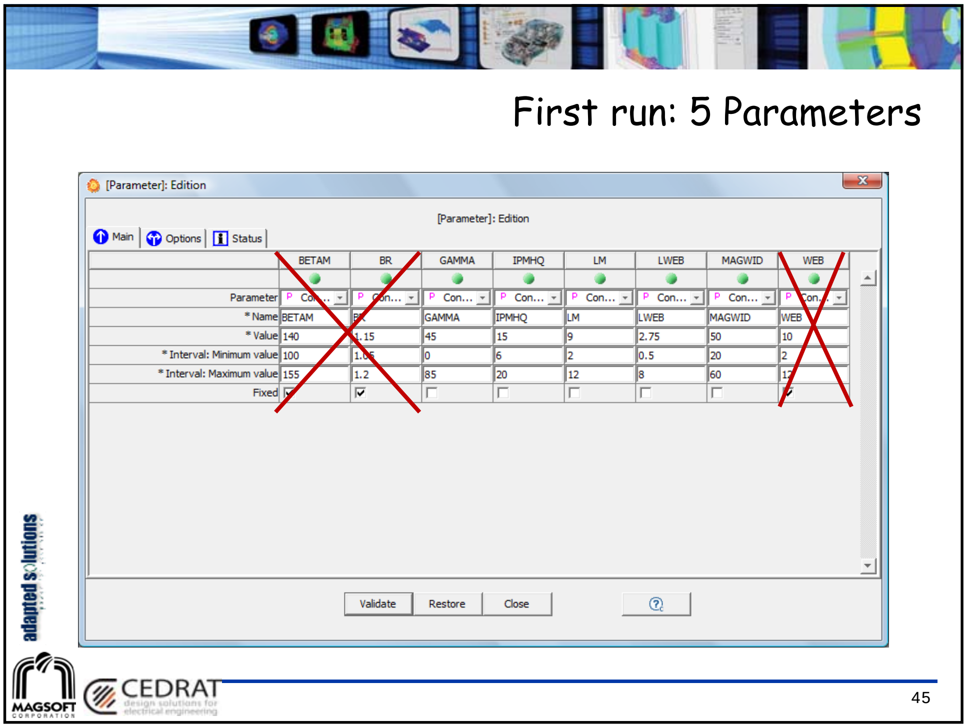
44


First run: 5 Parameters
[Parameter]: Edition
Main
Options
Status
BETAM
BR
GAMMA
IPMHQ
LM
LWEB
MAGWID
WEB
Parameter
* Name
* Value
* Interval: Minimum value
* Interval: Maximum value
Fixed
BETAM
GAMMA
IPMHQ
LM
LWEB
MAGWID
WEB
140
1.15
45
15
9
2.75
50
10
100
0
6
2
0.5
20
2
155
1.2
85
20
12
8
60
Validate
Restore
Close
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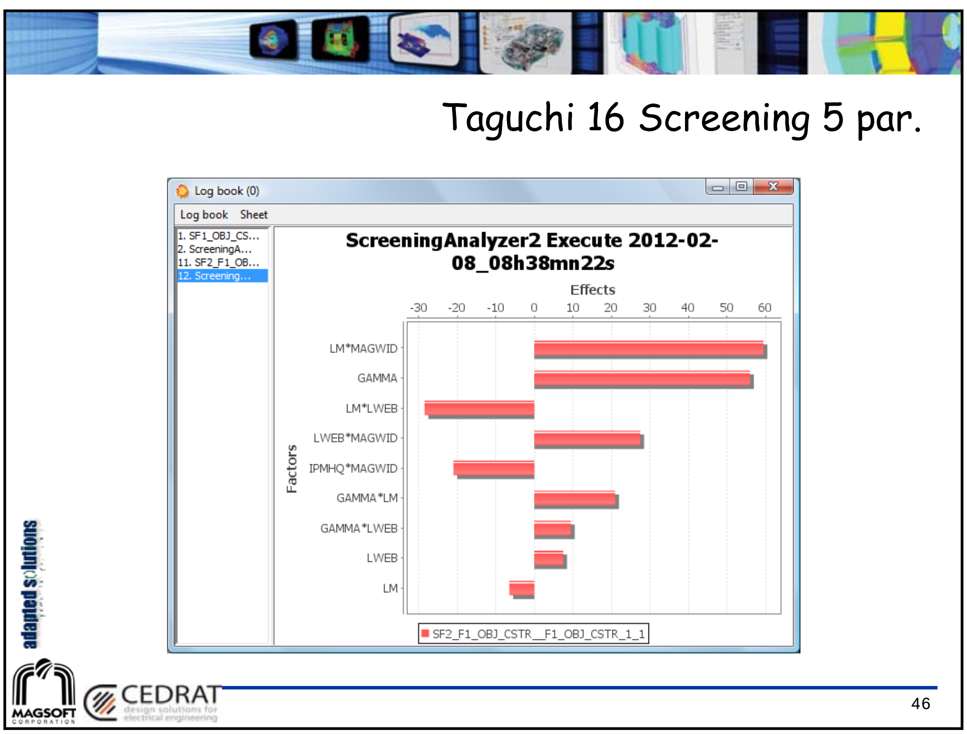
45


Taguchi 16 Screening 5 par.
Log book (0)
Log book
Sheet
1. SF1_OBJ_CS...
2. ScreeningA...
11. SF2_F1_OB...
12. Screening...
ScreeningAnalyzer2 Execute 2012-02-08_08h38mn22s
Effects
-30
-20
-10
0
10
20
30
40
50
60
Factors
LM*MAGWID
GAMMA
LM*LWEB
LWEB*MAGWID
IPMHQ*MAGWID
GAMMA*LM
GAMMA*LWEB
LWEB
LM
SF2_F1_OBJ_CSTR__F1_OBJ_CSTR_1_1
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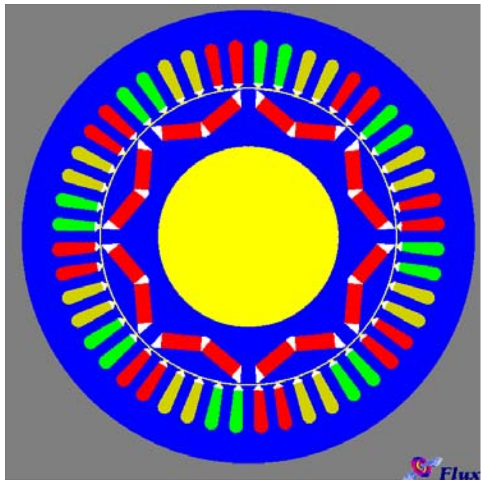
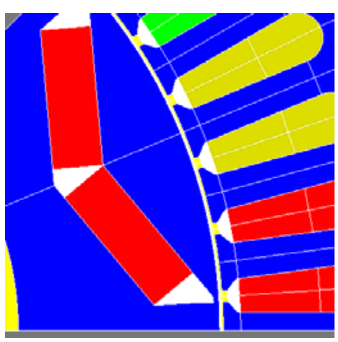
46

Improved Design – 5 Parameters

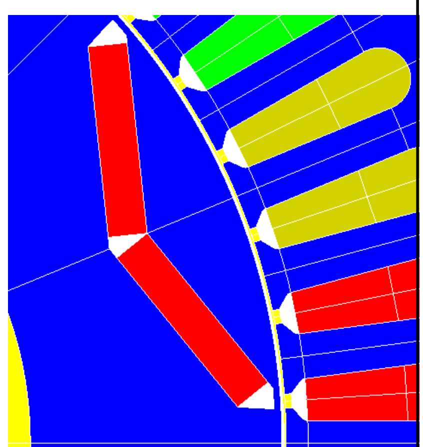


Magnet Xsection Area

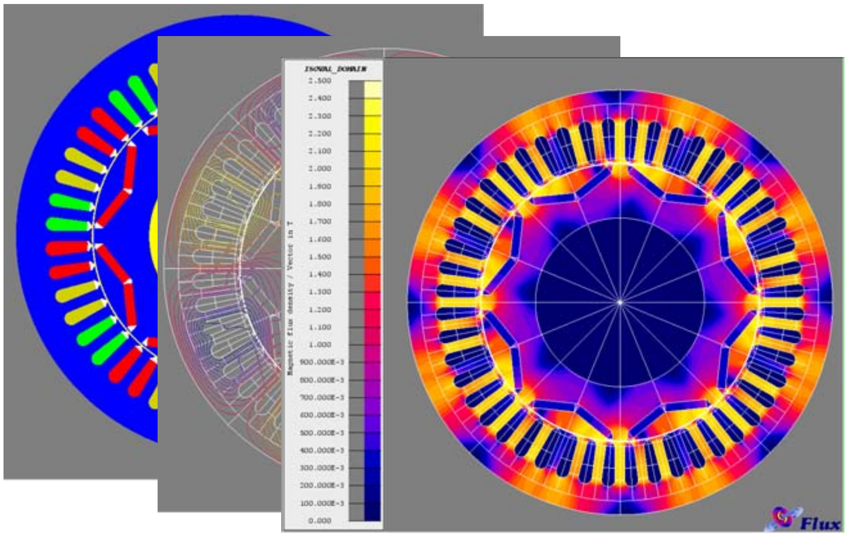
- Init – 450 mm^2



- Improved – 308 mm^2



Improved Design

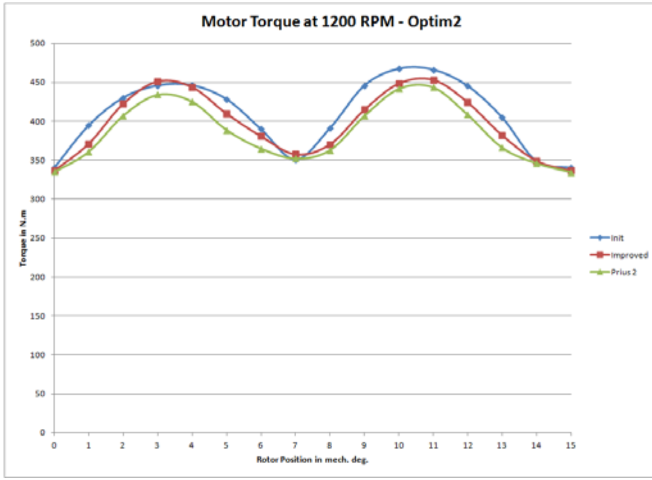


49

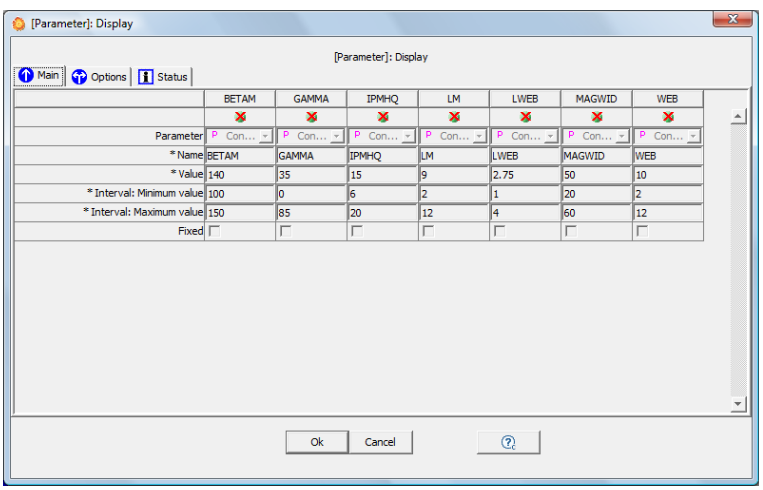
	Initial Design	Improved Design	Commercial Design	Units
BetaM	150	**140**	140	eDeg
IPMHQ	15	13.3	10	mm
LM	9	5.6	5	mm
MagWid	50	55	54	mm
Lm x MagWid	450	308	270	mm^2
Lweb	2.75	1.3	2.75	mm
Web	10	**10**	10	mm
Gamma	45	52	45	eDeg
Br	1.15	**1.15**	1.2	Tesla
Ave_Torque	413	401	390	N.m
Max_Torque	467	453	435	N.m
Min_Torque	340	337	344	N.m

50

IPM Torque @ 1200 RPM



Second run: 7 Parameters


[Parameter]: Display

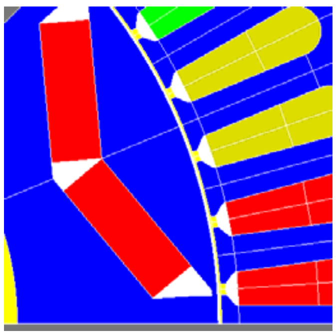
Main | Options | Status

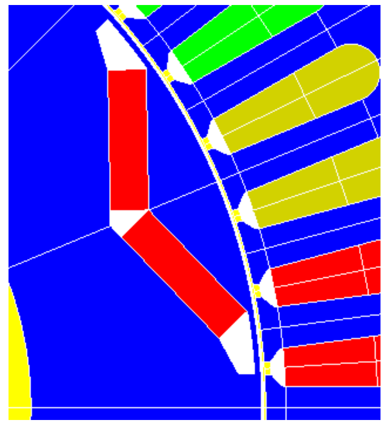
	BETAM	GAMMA	IPMHQ	LM	LWEB	MAGWID	WEB
Parameter	P Con...	P Con...	P Con...	P Con...	P Con...	P Con...	P Con...
* Name	BETAM	GAMMA	IPMHQ	LM	LWEB	MAGWID	WEB
* Value	140	35	15	9	2.75	50	10
* Interval: Minimum value	100	0	6	2	1	20	2
* Interval: Maximum value	150	85	20	12	4	60	12
Fixed	☐	☐	☐	☐	☐	☐	☐

Ok | Cancel

Magnet X-section Area

- Init – 450 mm^2
- Improved – 264 mm^2





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53

	Initial Design	Improved Des.	Commercial IDesign	Units
BetaM	140	105	140	eDeg
IPMHQ	15	11.5	10	mm
LM	9	6	5	mm
MagWid	50	44	54	mm
Lm x MagWid	450	264	270	mm^2
Lweb	2.75	2.65	2.75	mm
Web	10	10.6	10	mm
Gamma	35	52	45	eDeg
Br	1.15	**1.15**	1.2	Tesla
Ave_Torque	413	402	390	N.m
Max_Torque	467	447	435	N.m
Min_Torque	340	361	344	N.m

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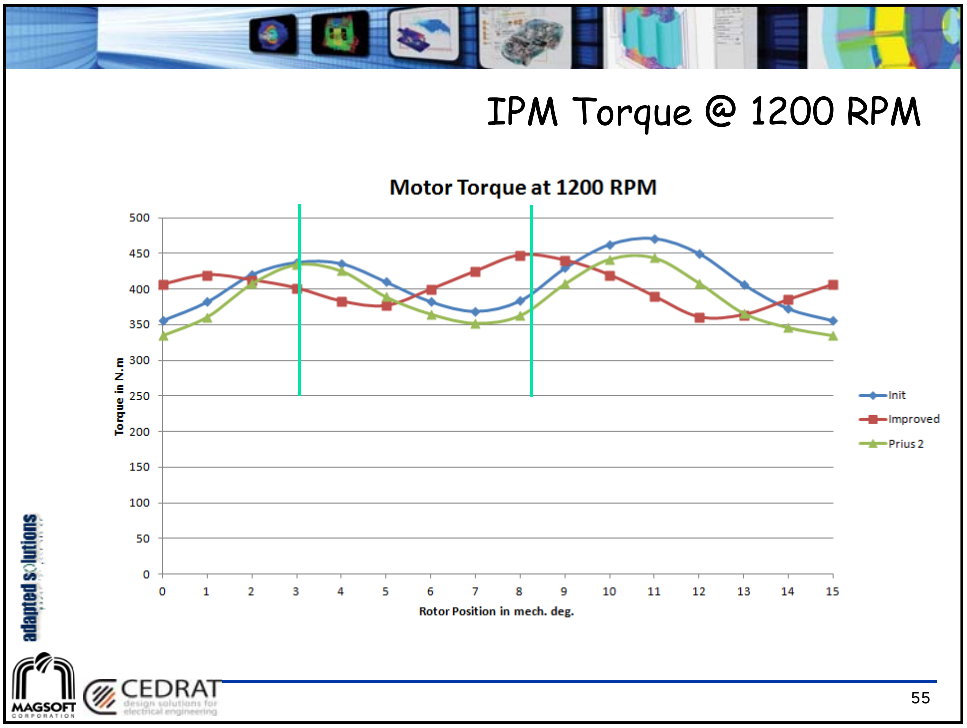
54


IPM Torque @ 1200 RPM
Motor Torque at 1200 RPM
Torque in N.m
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Rotor Position in mech. deg.
Init
Improved
Prius 2
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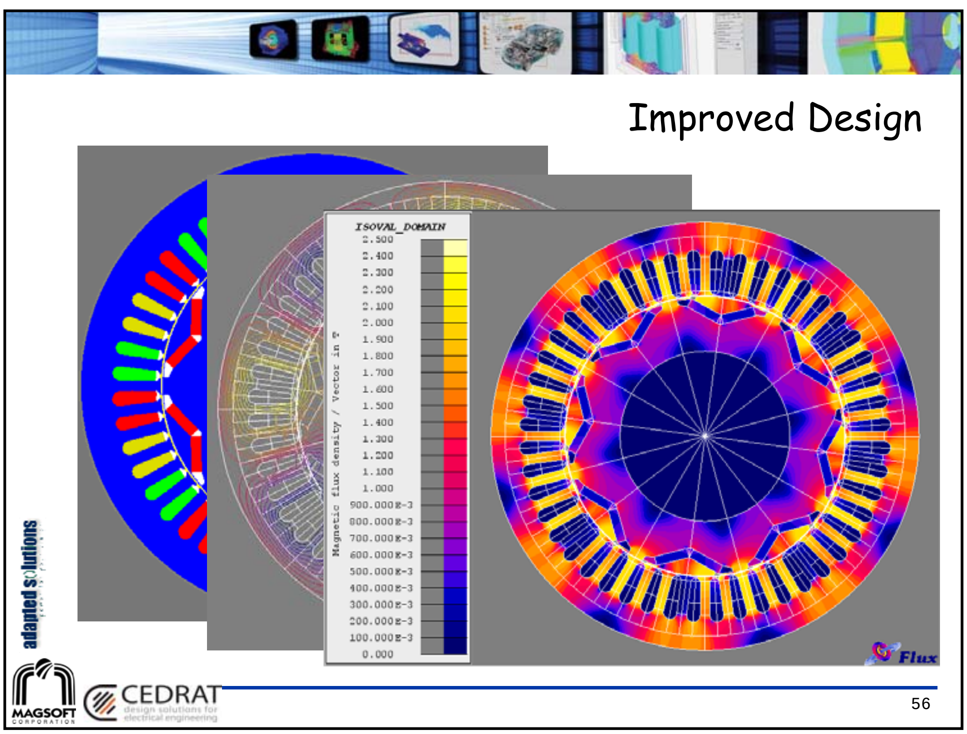
55


Improved Design
ISOVAL_DOMAIN
Magnetic flux density / Vector in T
2.500
2.400
2.300
2.200
2.100
2.000
1.900
1.800
1.700
1.600
1.500
1.400
1.300
1.200
1.100
1.000
900.000E-3
800.000E-3
700.000E-3
600.000E-3
500.000E-3
400.000E-3
300.000E-3
200.000E-3
100.000E-3
0.000
Flux
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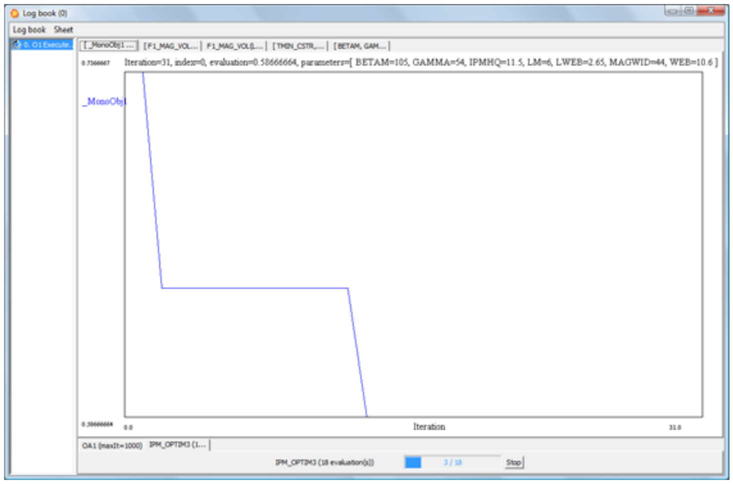
56

Objective Function Convergence



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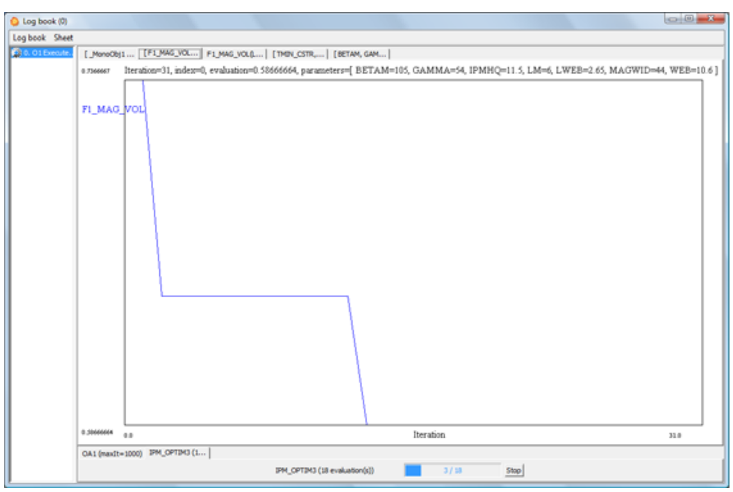
57

PU Magnet Volume



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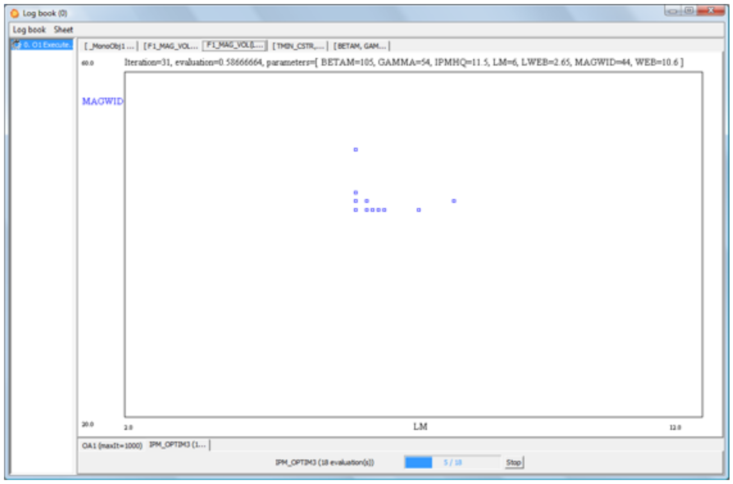
58

Evaluation of MagWid & LM



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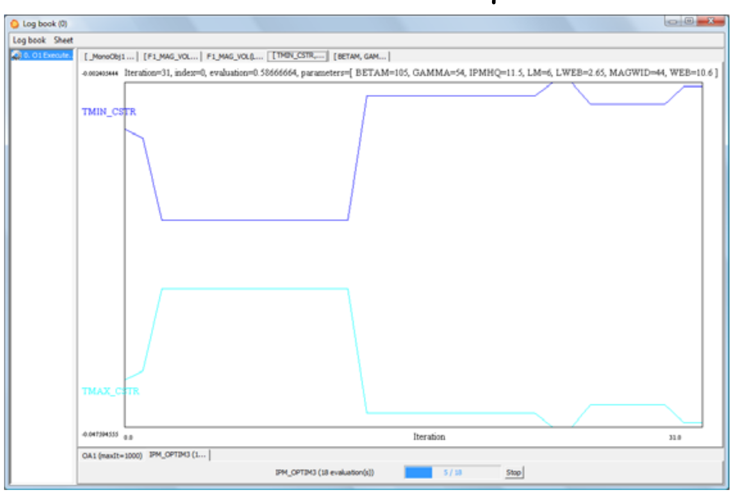
59

Torque Constraints



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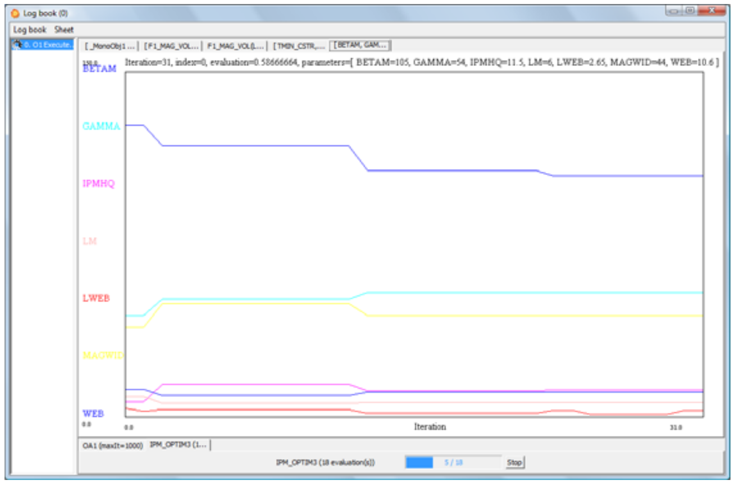
60

Parameters



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61

Optimization Induction Machine

Change the rotor bar material from aluminum to copper.

Change the rotor bar shape to keep the same lock rotor torque as initial aluminum rotor bar.

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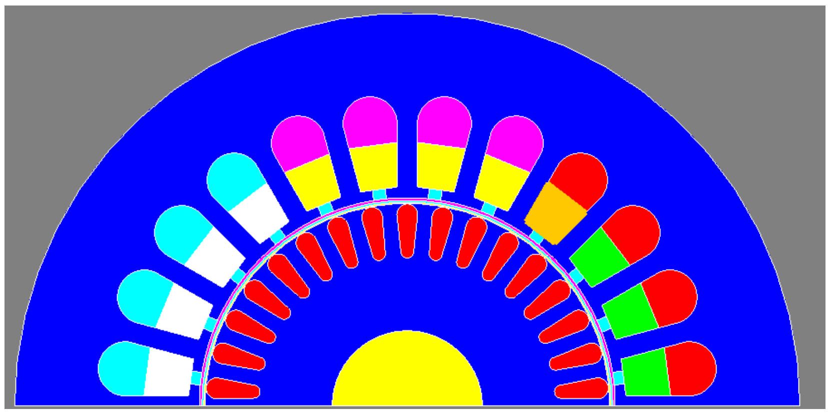
62

Initial model

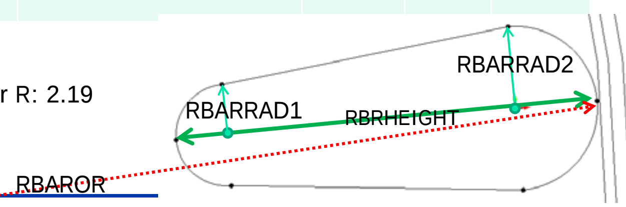


Parameter range

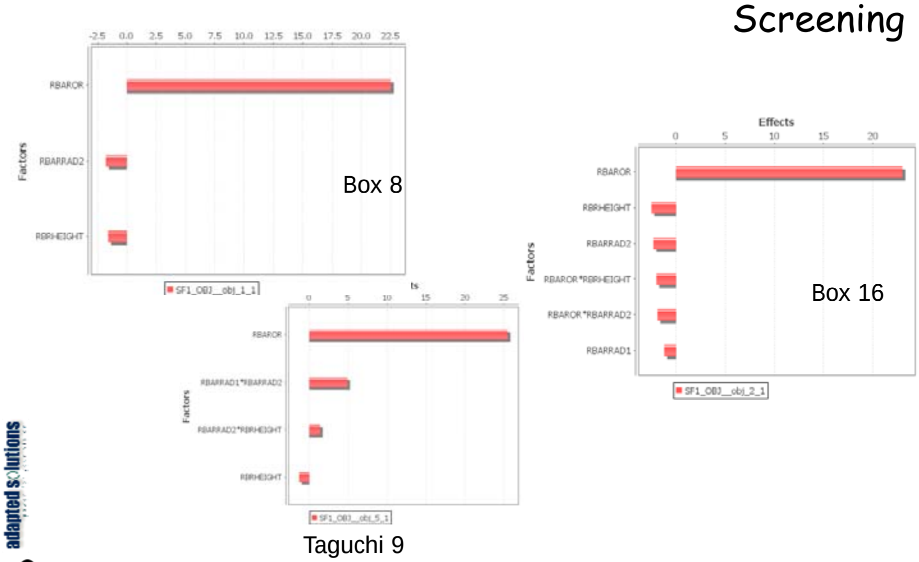
Parameter	Comment	Initial	Min	Max
RBAROR	Rotor bar outer R	2.185	1.8	2.185
RBARRAD1	Rotor bar bottom R	0.07	0.03	0.08
RBARRAD2	Rotor bar up R	0.113	0.05	0.15
RBRHEIGHT	Rotor bar R	0.584	0.15	0.8

UNIT: inch

Rotor outer R: 2.19



Screening



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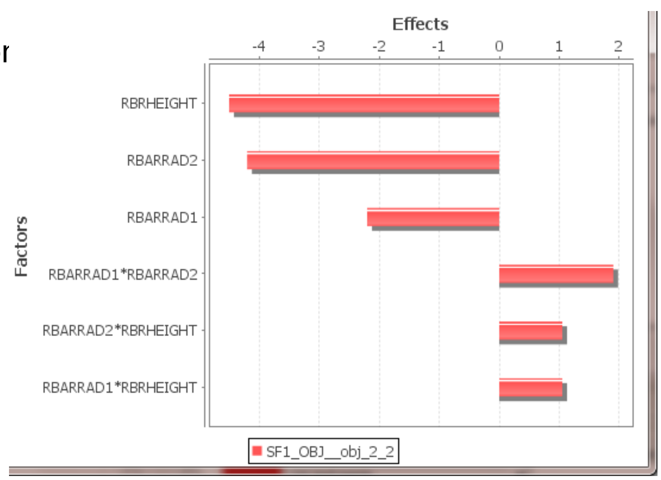
65

Fixed RBAROR

Box 8 or



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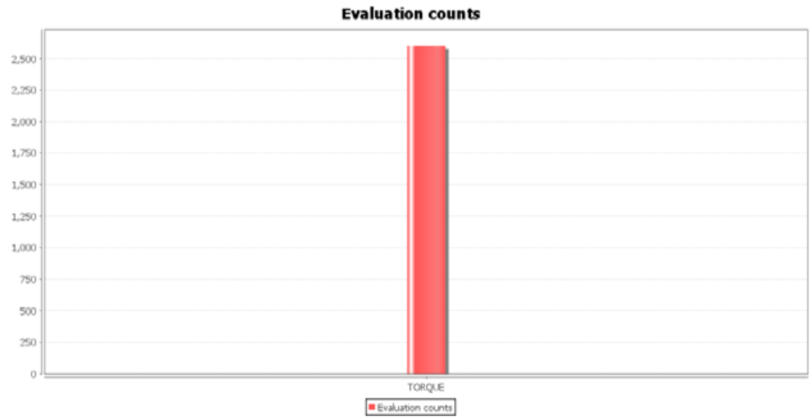
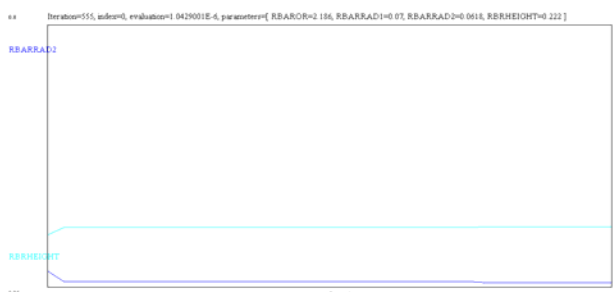
66

Start optimization for lock rotor

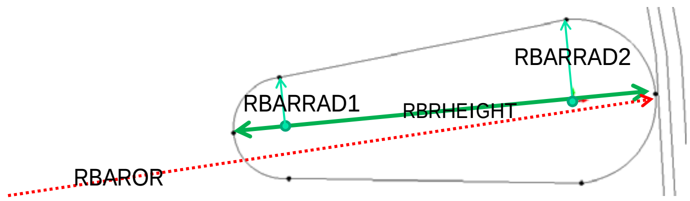
Fixed RBAROR and RBARRAD1





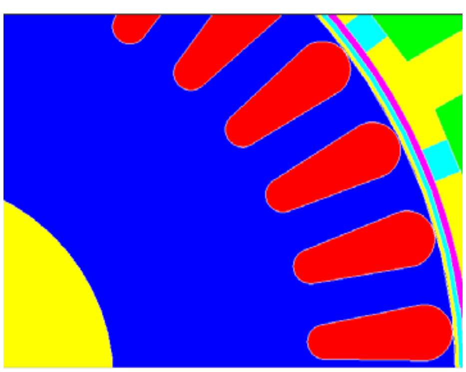
Parameter range

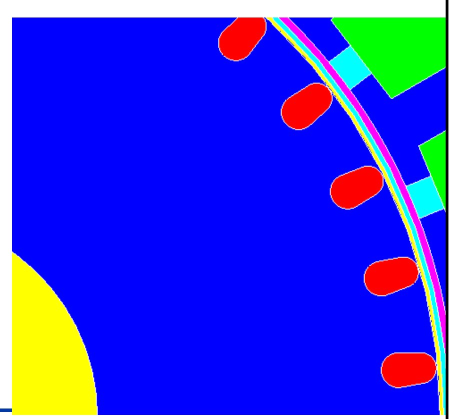
Parameter	Comment	Initial	Min	Max	final
RBAROR	Rotor bar outer R	2.185	fixed		
RBARRAD1	Rotor bar bottom R	0.07			
RBARRAD2	Rotor bar up R	0.113	0.05	0.15	0.0618
RBRHEIGHT	Rotor bar R	0.584	0.15	0.8	0.222



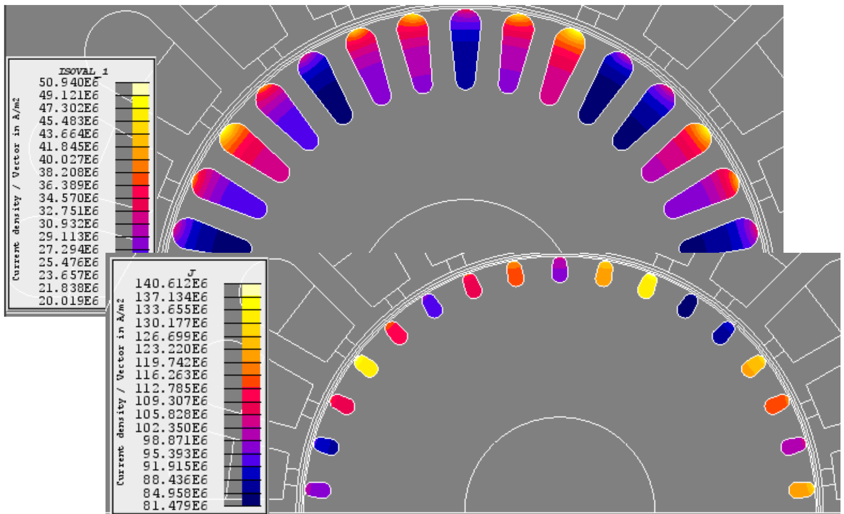
UNIT: inch

Geometry optimized for locked rotor condition





Current density



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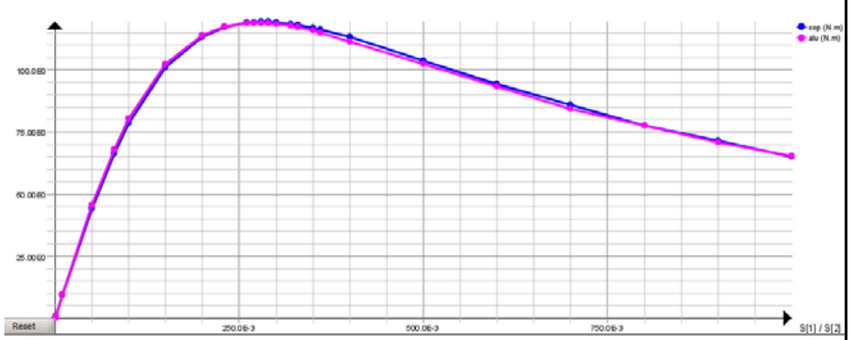
71

Copper

Aluminum



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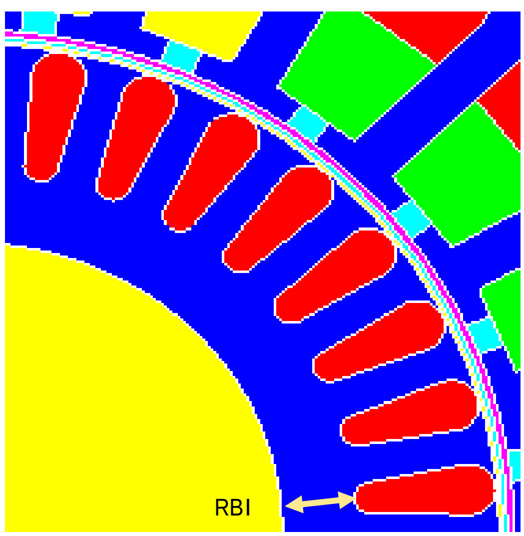
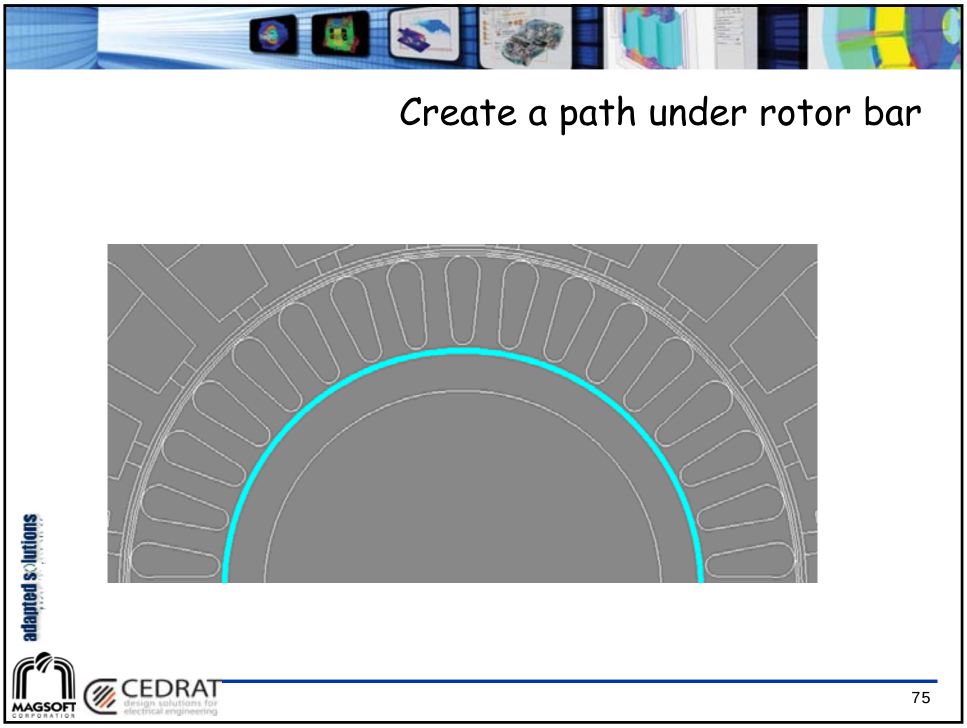
72

Optimization case2 multi objective

Decrease rotor yoke iron depth to make machine lighter.
Also keep the flux density in rotor yoke under saturation.
Add a parameter RBI (yoke iron depth)




Create a path under rotor bar
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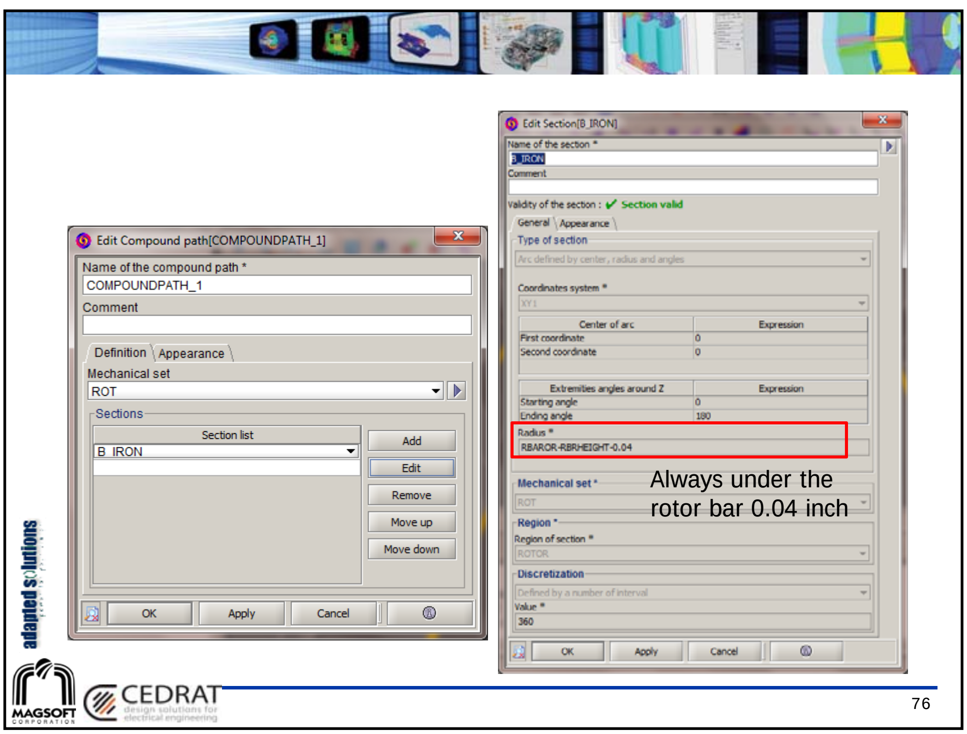
75


Edit Compound path[COMPOUNDPATH_1]
Name of the compound path *
COMPOUNDPATH_1
Comment
Definition
Appearance
Mechanical set
ROT
Sections
Section list
B_IRON
Add
Edit
Remove
Move up
Move down
OK
Apply
Cancel
Edit Section[B_IRON]
Name of the section *
B_IRON
Comment
Validity of the section : Section valid
General
Appearance
Type of section
Coordinates system *
Center of arc
Expression
First coordinate
0
Second coordinate
0
Extremities angles around Z
Expression
Starting angle
0
Ending angle
180
Radius *
RBAROR-RBRHEIGHT-0.04
Mechanical set *
Region *
Region of section *
Discretization
Value *
360
OK
Apply
Cancel
Always under the rotor bar 0.04 inch
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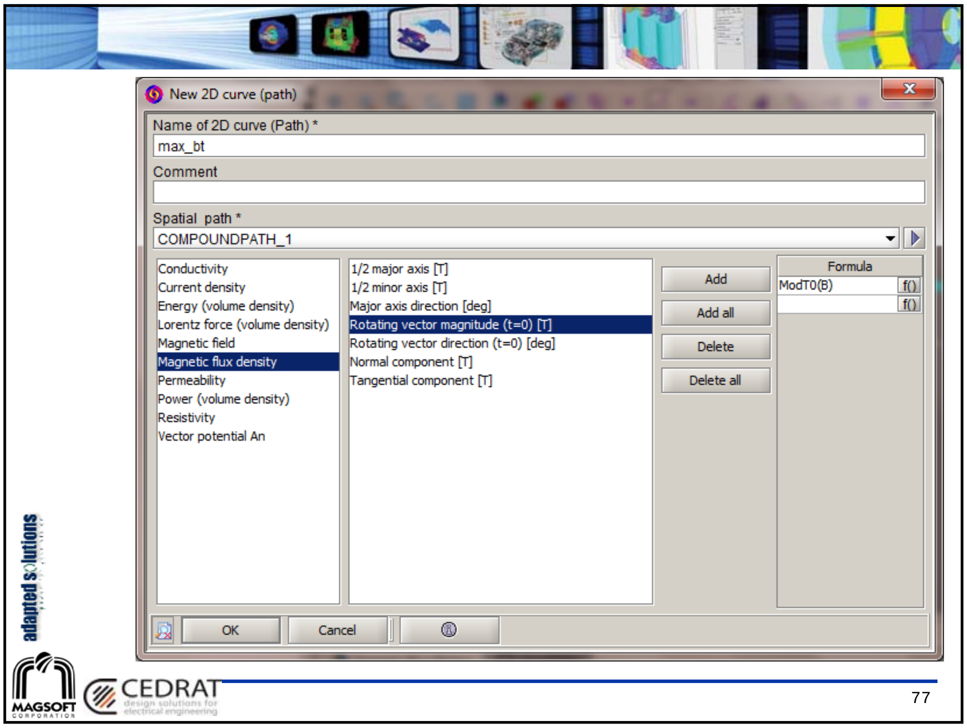
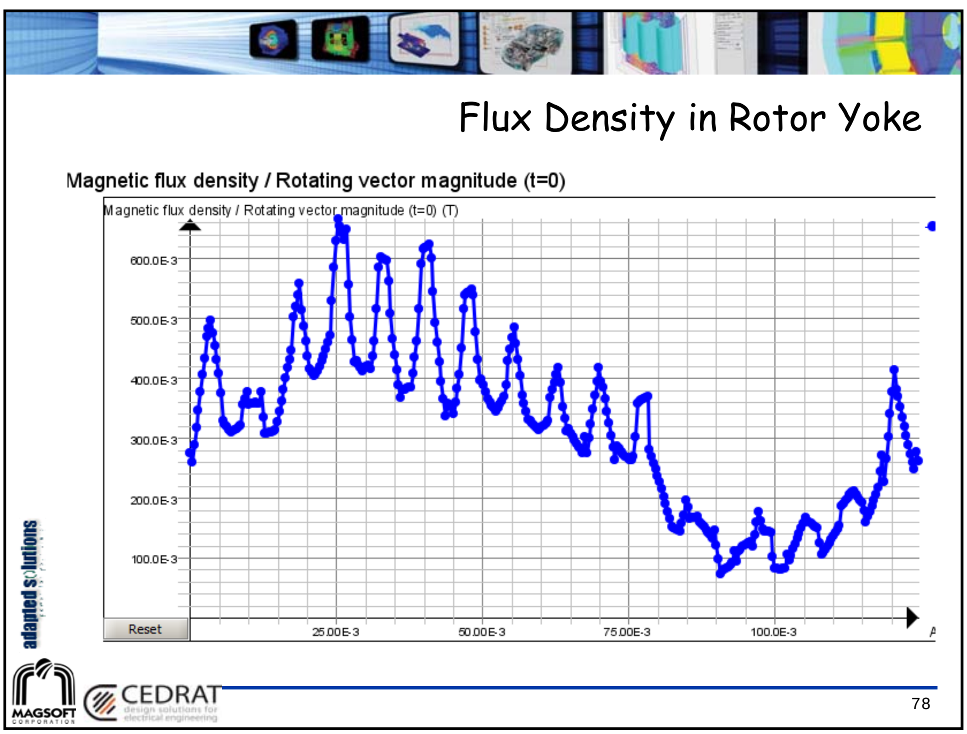
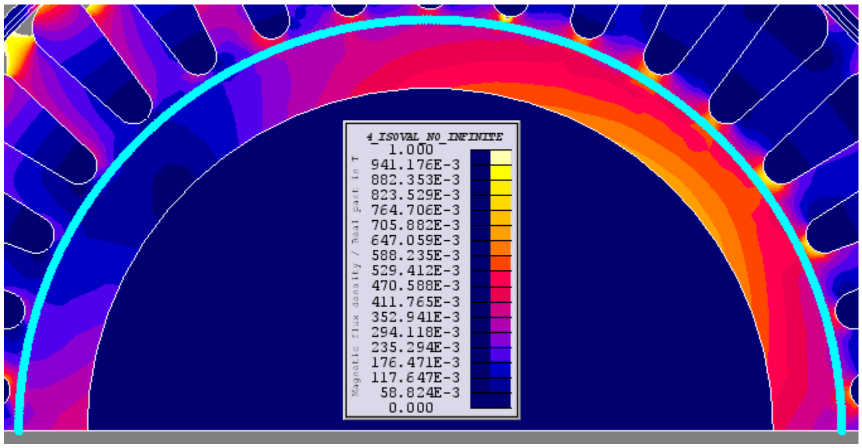
76


New 2D curve (path)
Name of 2D curve (Path) *
max_bt
Comment
Spatial path *
COMPOUNDPATH_1
Conductivity
Current density
Energy (volume density)
Lorentz force (volume density)
Magnetic field
Magnetic flux density
Permeability
Power (volume density)
Resistivity
Vector potential An
1/2 major axis [T]
1/2 minor axis [T]
Major axis direction [deg]
Rotating vector magnitude (t=0) [T]
Rotating vector direction (t=0) [deg]
Normal component [T]
Tangential component [T]
Add
Add all
Delete
Delete all
Formula
ModT0(B)
OK
Cancel
CEDRAT
77


Flux Density in Rotor Yoke
Magnetic flux density / Rotating vector magnitude (t=0)
Magnetic flux density / Rotating vector magnitude (t=0) (T)
600.0E-3
500.0E-3
400.0E-3
300.0E-3
200.0E-3
100.0E-3
Reset
25.00E-3
50.00E-3
75.00E-3
100.0E-3
CEDRAT
78

Bmag Distribution after Optimization



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Py FILE

```
#! Flux2D 11.1

CurveVariation2D[ALL].delete()
CurveSpatial2D[ALL].delete()


startMacroTransaction()
ComputePhysicTransient['ComputePhysic'].storageName='ComputePhysic_1'

ComputePhysicTransient['ComputePhysic'].formula=['TorqueElecMag(ROT)']

endMacroTransaction()

VariationParameter['TORQUE'].formula=['TorqueElecMag(ROT)']

SpatialCurve(name='Flux_den_RBI',
        compoundPath=CompoundPath['COMPOUNDPATH_1'],
        formula=['ModT0(B)'])


BIB=CurveVariation2D['Flux_den_RBI'].y[0].maximalValues[0]
VariationParameter['BT'].formula=str(BIB)
```

You must create path and keep it before generate .F2G file
You can't create path in optimization.

Set BT as the max value on the back iron path

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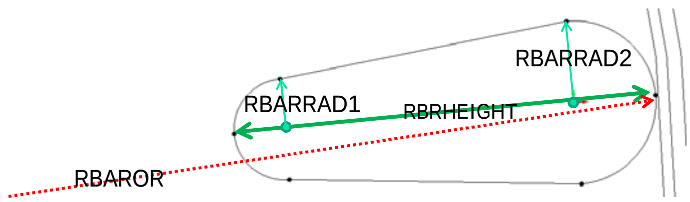
Parameter range

Parameter	Comment	Initial	Min	Max	final
RBARRAD2	Rotor bar up R	0.113	0.05	0.15	0.0618
RBRHEIGHT	Rotor bar R	0.584	0.15	0.8	0.222
RBI	Rotor back iron depth	0.3	0.2	0.7	0.239



UNIT: inch

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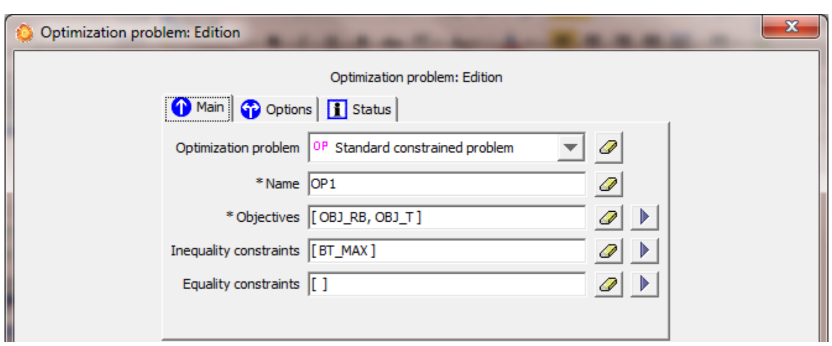
81

Objective functions

1. the same lock rotor torque.
2. decrease the rotor back iron depth



adapted solutions

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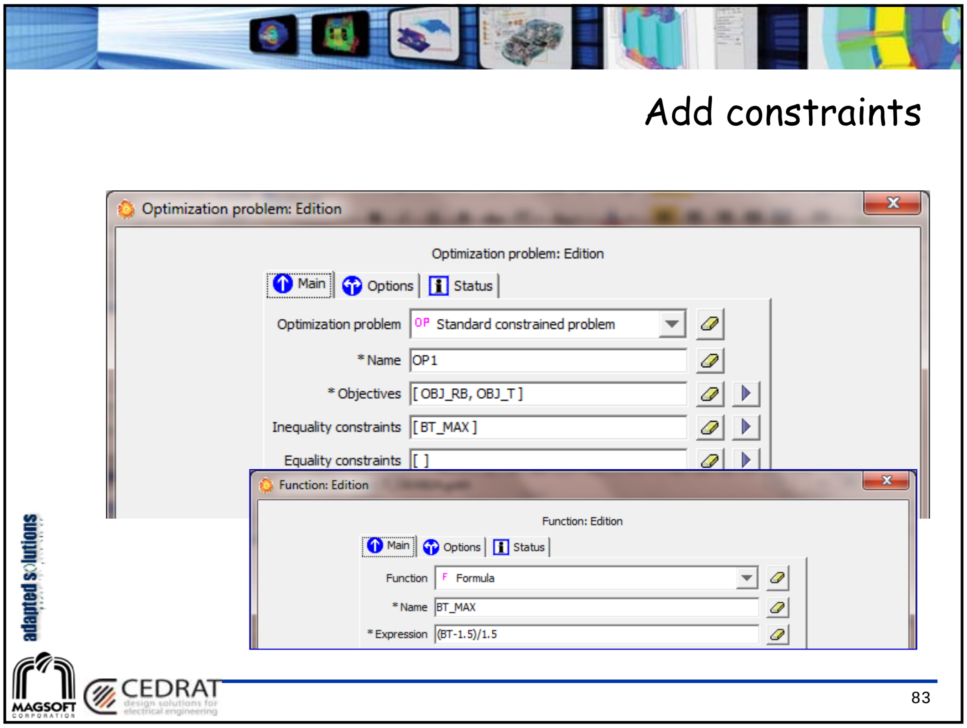
82


Add constraints
Optimization problem: Edition
Optimization problem: Edition
Main
Options
Status
Optimization problem
Standard constrained problem
* Name
OP1
* Objectives
[OBJ_RB, OBJ_T]
Inequality constraints
[BT_MAX]
Equality constraints
[ ]
Function: Edition
Function: Edition
Main
Options
Status
Function
Formula
* Name
BT_MAX
* Expression
(BT-1.5)/1.5
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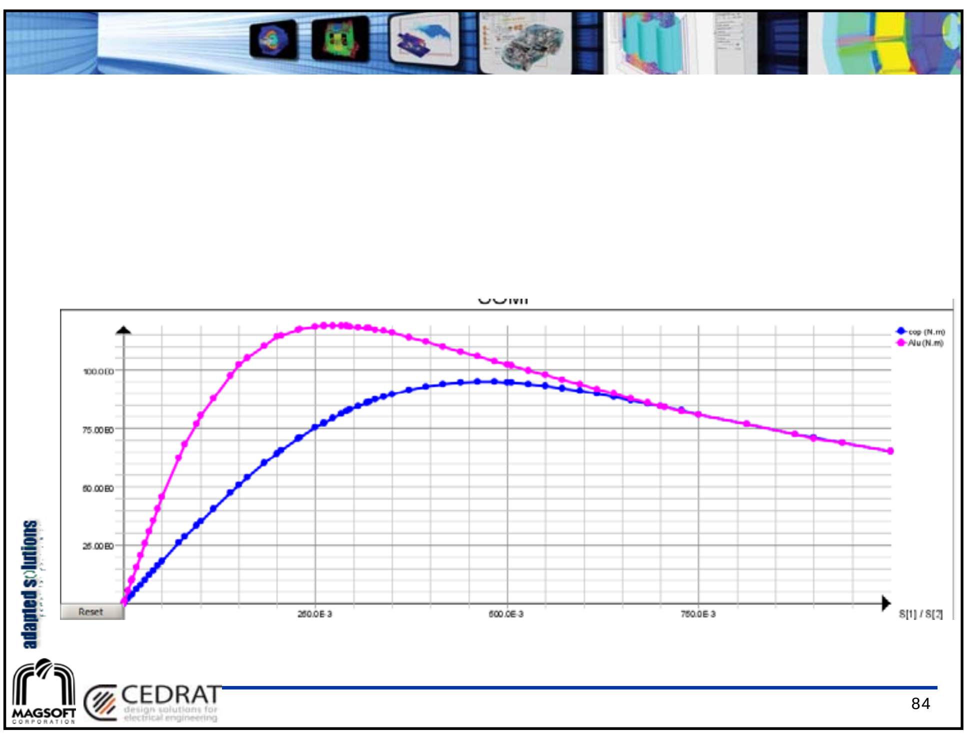
83


Reset
250.0E-3
500.0E-3
750.0E-3
S[1] / S[2]
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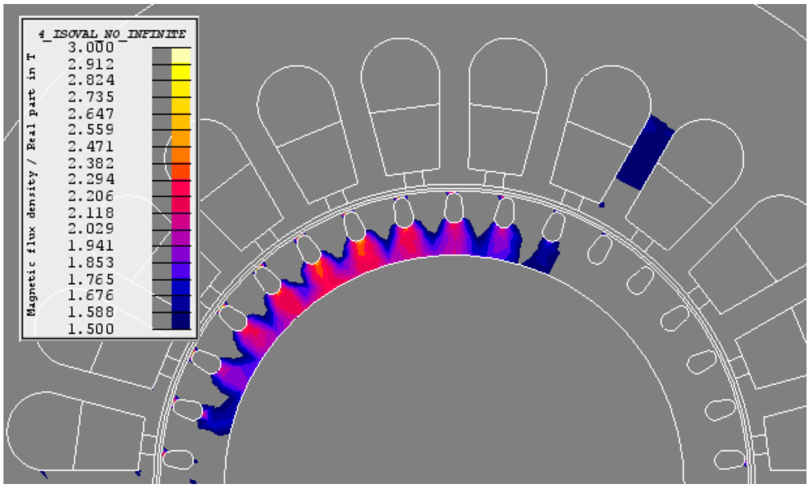
84

Flux density at slip = 0.277



Optimization Induction Machine 2

Change the rotor bar material from aluminum to copper.

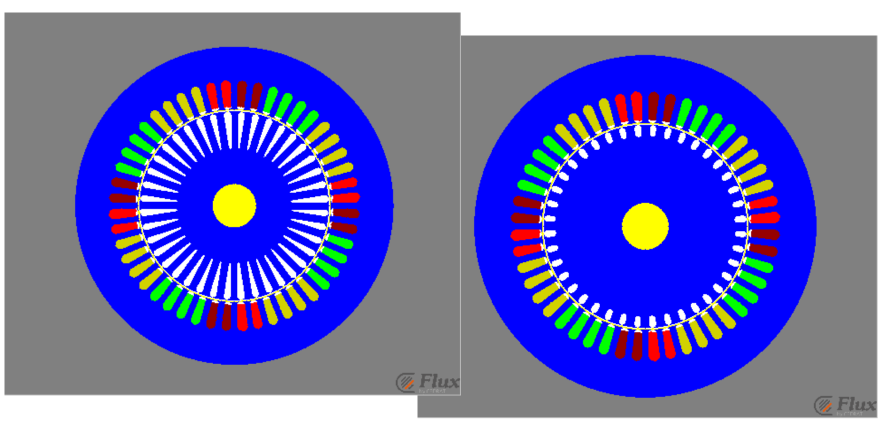
Change the rotor bar shape to keep the same lock rotor torque as initial aluminum rotor bar.

1st Initial model Parameter range

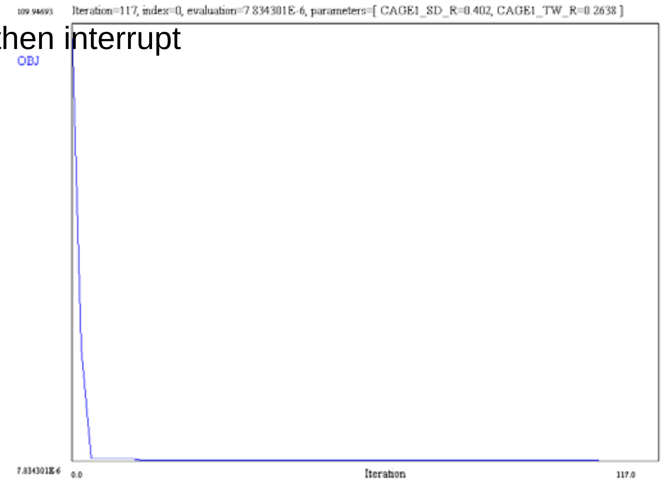
Parameter	Comment	Initial	Min	Max	final
CAGE1_SD_R	Rotor bar slot depth	1.4	0.4	1.5	0.402
CAGE1_TW_R	Rotor tooth width	0.25	0.2	0.3	0.263 8

Copper resistivity: 2.2e-8

Lock rotor torque 426.317 Nm



117 iteration then interrupt



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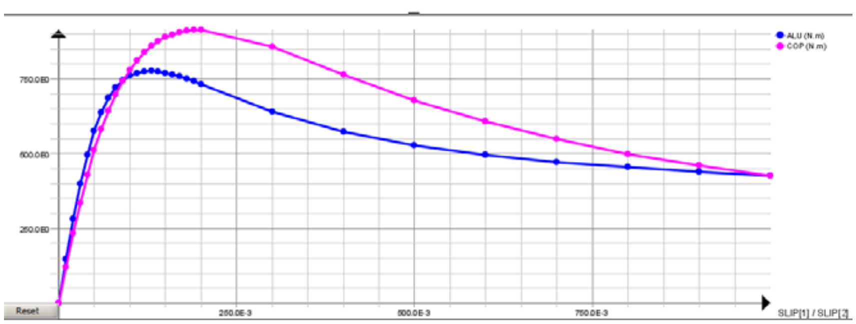
89

Torque – slip



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90

Power balance

Alu rated slip = 0.0175	input power	-48677.98	speed(rpm)	1768.5
	stator loss	1592.90	T (Nm)	**248.581**
	rotor loss	**725.86**	Pout	46036.4273
	total loss	2494.53	Eff	0.9486
	power diff	-147.02		
	diff %	-0.003020297		
cop slip = 0.0175	input power	-39990.71	speed(rpm)	1768.5
	stator loss	1031.53	T (Nm)	**205.1822**
	rotor loss	**644.19**	Pout	37999.1047
	total loss	1872.67	Eff	0.95303
	power diff	-118.94		
	diff %	0.002974194		
cop slip = 0.0213 The same torque	input power	-48180.67	speed(rpm)	1761.66
	stator loss	1405.64	T (Nm)	**246.709**
	rotor loss	**941.42**	Pout	45513.0253
	total loss	2544.01	Eff	0.94706
	power diff	-123.64		
	diff %	0.002566		

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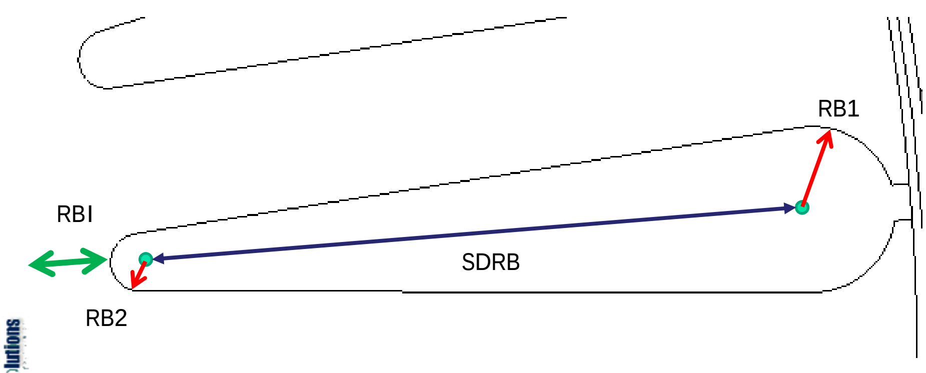
Change rotor model



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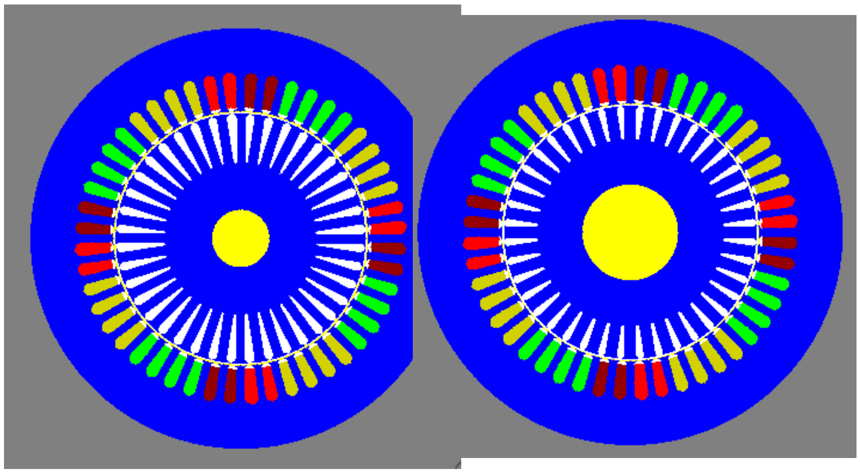
2^{nd} optimization for locked rotor torque

Parameter range 8 iteration interrupt

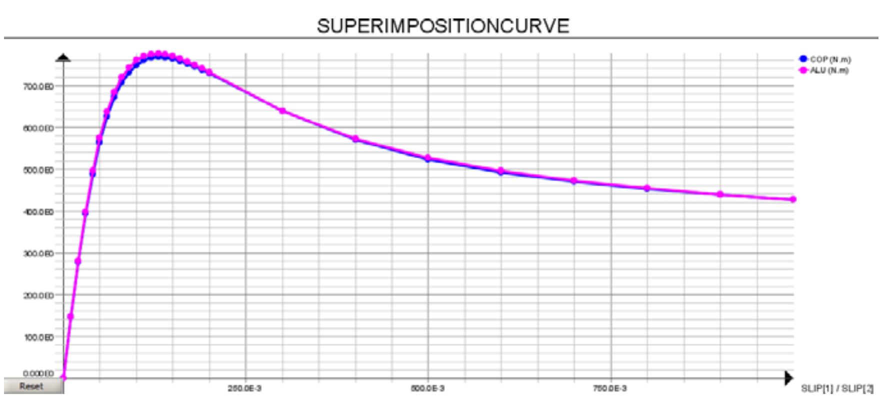
Parameter	Comment	Initial	Min	Max	final
RB1	Rotor bar top radius	0.143	0.06	0.17	0.0912
RB2	Rotor bar bottom radius	0.05	0.01	0.11	0.02944
SDRB	Rotor bar slot depth	1.1633	0.1	1.3	0.803

Torque - 426.184 Nm only
0.13 Nm difference with Alu
for 9-hr solving period time

Copper resistivity: 2.2e-8



Torque – slip


SUPERIMPOSITIONCURVE
COP (N.m)
ALU (N.m)
700.0E0
600.0E0
500.0E0
400.0E0
300.0E0
200.0E0
100.0E0
0.000E0
Reset
250.0E-3
500.0E-3
750.0E-3
SLIP[1] / SLIP[2]

Power balance

Alu
rated
slip = 0.0175

input power	-48677.98	speed(rpm)	1768.5
stator loss	1592.90	T (Nm)	**248.581**
rotor loss	**725.86**	Pout	46036.4273
total loss	2494.53	Eff	0.9486
power diff	-147.02	Rotor bar area(mm2) (each)	173.8
diff %	-0.003020297	Rotor iron area(mm2) (1/4)	4446

cop
slip = 0.0175

input power	-48384.68	speed(rpm)	1768.5
stator loss	1435.74	T (Nm)	**247.0765**
rotor loss	**765.86**	Pout	45757.7986
total loss	2397.72	Eff	0.95021
power diff	-229.16	Rotor bar area(mm2) (each)	73.1
diff %	0.004736283	Rotor iron area(mm2) (1/4)	5607

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97

3^{rd} optimization for rated speed rotor torque

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98

Parameter range

Parameter	Comment	Initial	Min	Max	final
RB1	Rotor bar top radius	fixed			0.0912
RB2	Rotor bar bottom radius	0.02944	0.01	0.11	0.1031
SDRB	Rotor bar slot depth	0.803	0.1	1.3	1.19
RBI	Rotor back iron depth	1.3	0.7	2	0.424

Torque – 248.524 Nm only
0.057 Nm difference with Alu

Copper resistivity: 2.2e-8

Py FILE

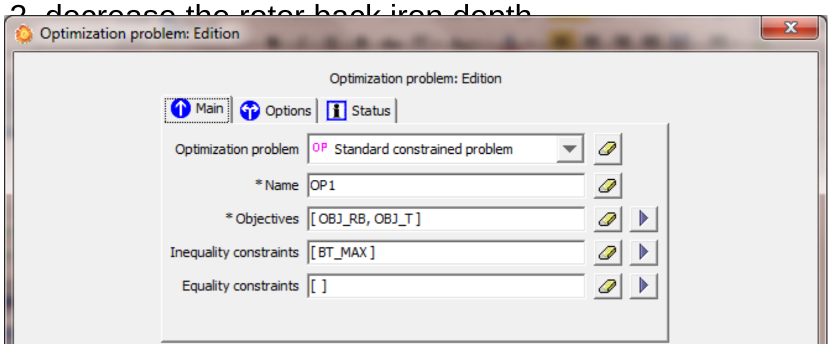
```
#! Flux2D 11.1

CurveVariation2D[ALL].delete()
CurveSpatial2D[ALL].delete()


startMacroTransaction()
ComputePhysicTransient['ComputePhysic'].storageName='ComputePhysic_1'

ComputePhysicTransient['ComputePhysic'].formula=['TorqueElecMag(ROT)']

endMacroTransaction()

VariationParameter['TORQUE'].formula=['TorqueElecMag(ROT)']

SpatialCurve(name='Flux_den_RBI',
        compoundPath=CompoundPath['COMPOUNDPATH_1'],
        formula=['ModT0(B)'])

BIB=CurveVariation2D['Flux_den_RBI'].y[0].maximalValues[0]
VariationParameter['BT'].formula=str(BIB)
```

You must create path and keep it before generate .F2G file
You can't create path in optimization.

Set BT as the max value on the back iron path

Obj functions

1. the same rated speed torque.
2. decrease the rotor back iron depth



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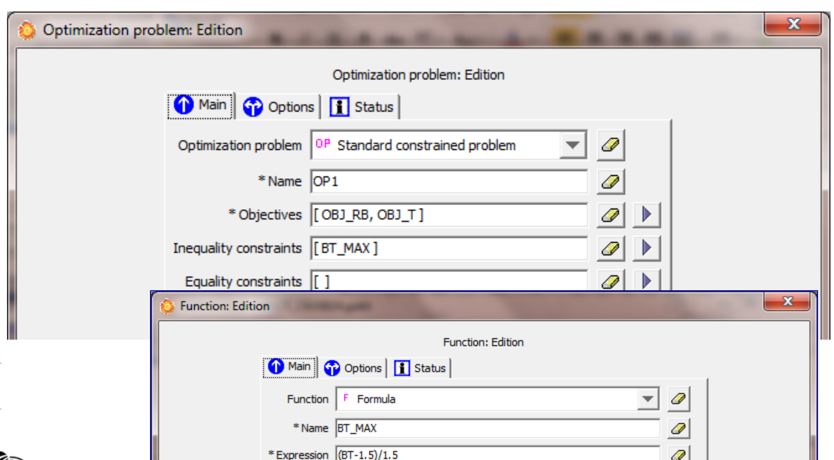
Add constraints



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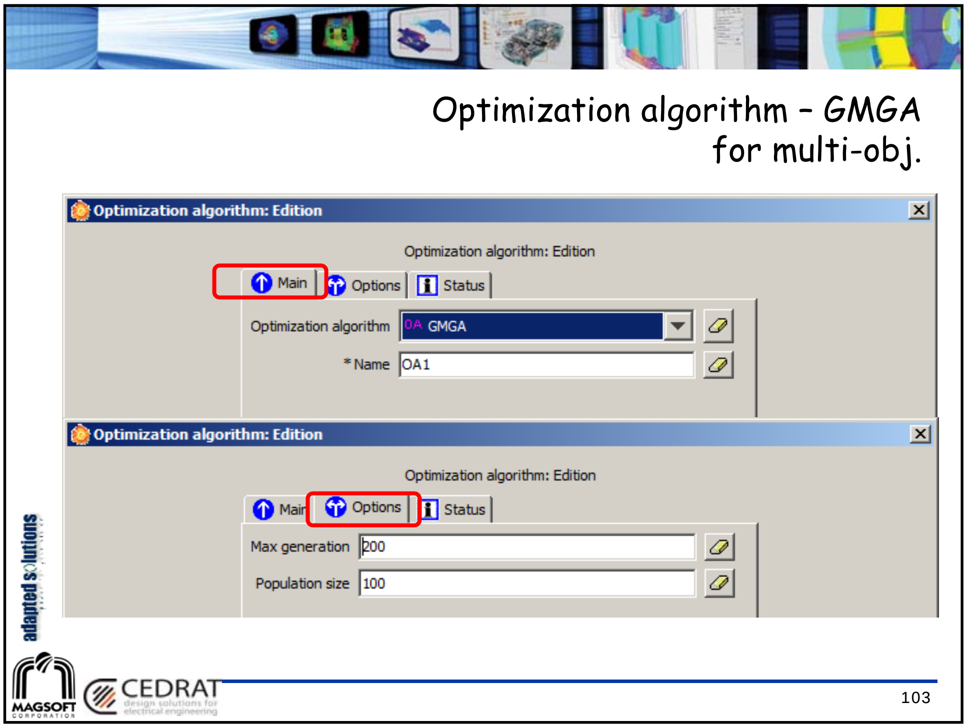
Optimization algorithm – GMGA for multi-obj.
Optimization algorithm: Edition
Optimization algorithm: Edition
Main
Options
Status
Optimization algorithm
GMGA
* Name
OA1
Optimization algorithm: Edition
Optimization algorithm: Edition
Main
Options
Status
Max generation
200
Population size
100
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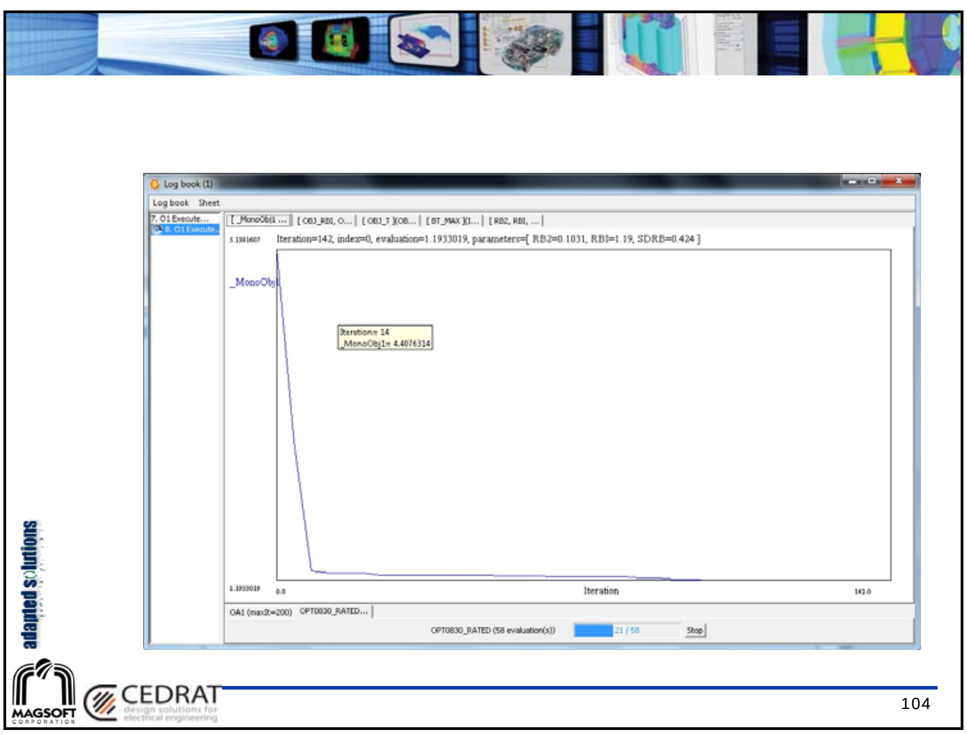
103


Log book
Iteration=142, index=0, evaluation=1.1933019, parameters=[RB2=0.1031, RBI=1.19, SDRB=0.424]
_MonoObj1
Iteration
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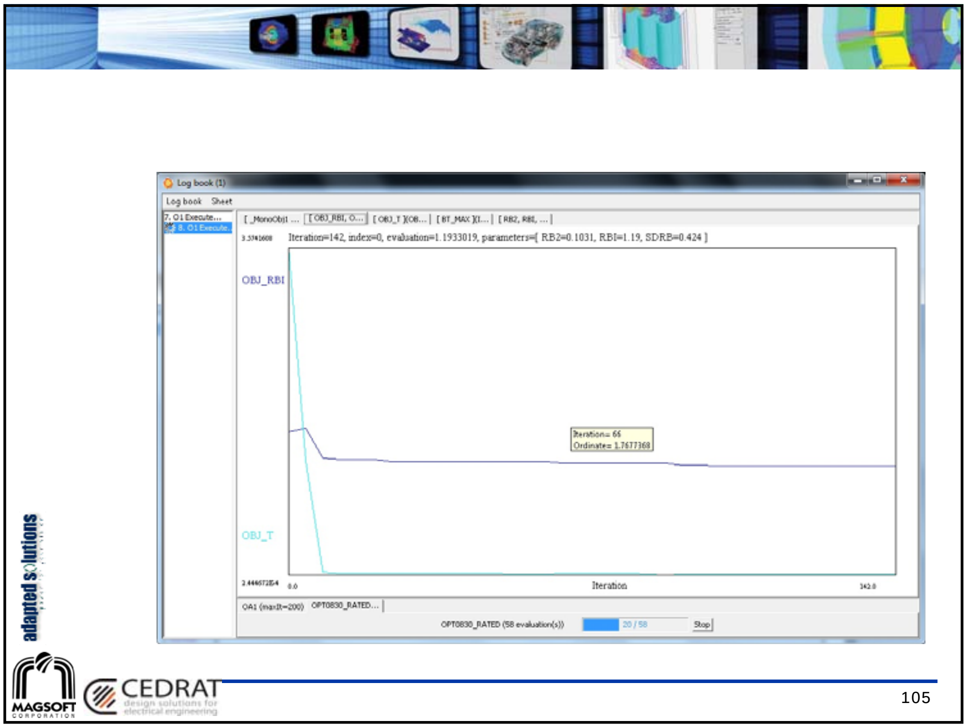
104


Log book (1)
Log book Sheet
7. O1 Execute...
8. O1 Execute...
[_MonoObj1 ... | [OBJ_RBI, O... | [OBJ_T](OB... | [BT_MAX](1... | [RB2, RBI, ... |
Iteration=142, index=0, evaluation=1.1933019, parameters=[RB2=0.1031, RBI=1.19, SDRB=0.424]
OBJ_RBI
Iteration= 66
Ordinate= 1.7677368
OBJ_T
0.0
Iteration
142.0
OA1 (maxIt=200) OPT0830_RATED...
OPT0830_RATED (58 evaluation(s))
20 / 58
Stop
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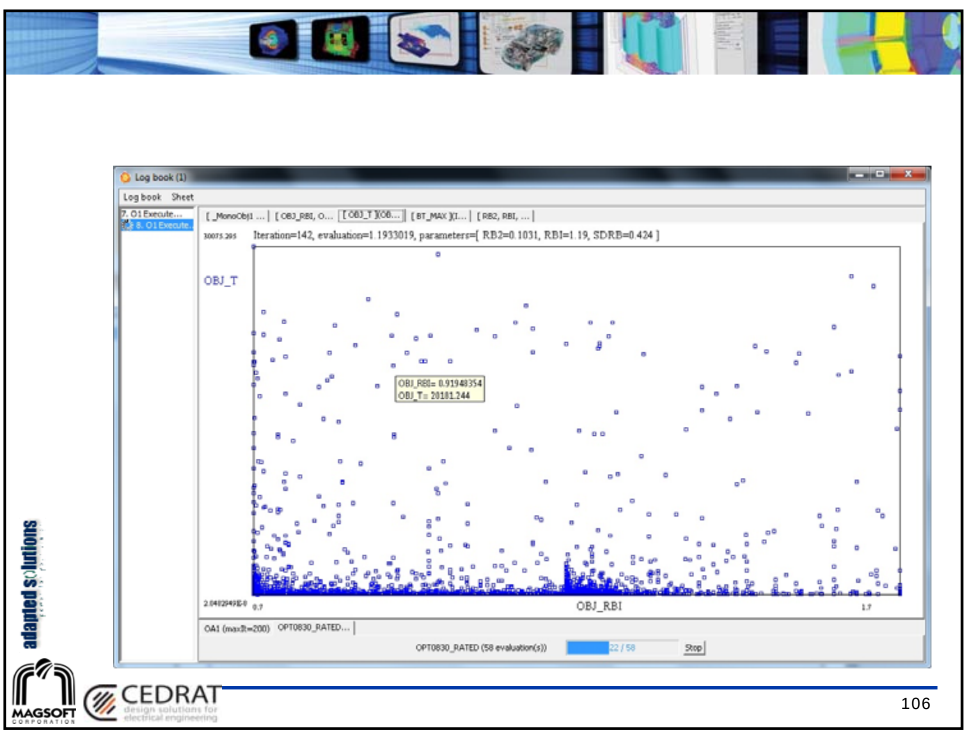
105


Log book (1)
Log book Sheet
7. O1 Execute...
8. O1 Execute...
[_MonoObj1 ... | [OBJ_RBI, O... | [OBJ_T](OB... | [BT_MAX](1... | [RB2, RBI, ... |
Iteration=142, evaluation=1.1933019, parameters=[RB2=0.1031, RBI=1.19, SDRB=0.424]
OBJ_T
OBJ_RBI= 0.91948354
OBJ_T= 20181.244
0.7
OBJ_RBI
1.7
OA1 (maxIt=200) OPT0830_RATED...
OPT0830_RATED (58 evaluation(s))
22 / 58
Stop
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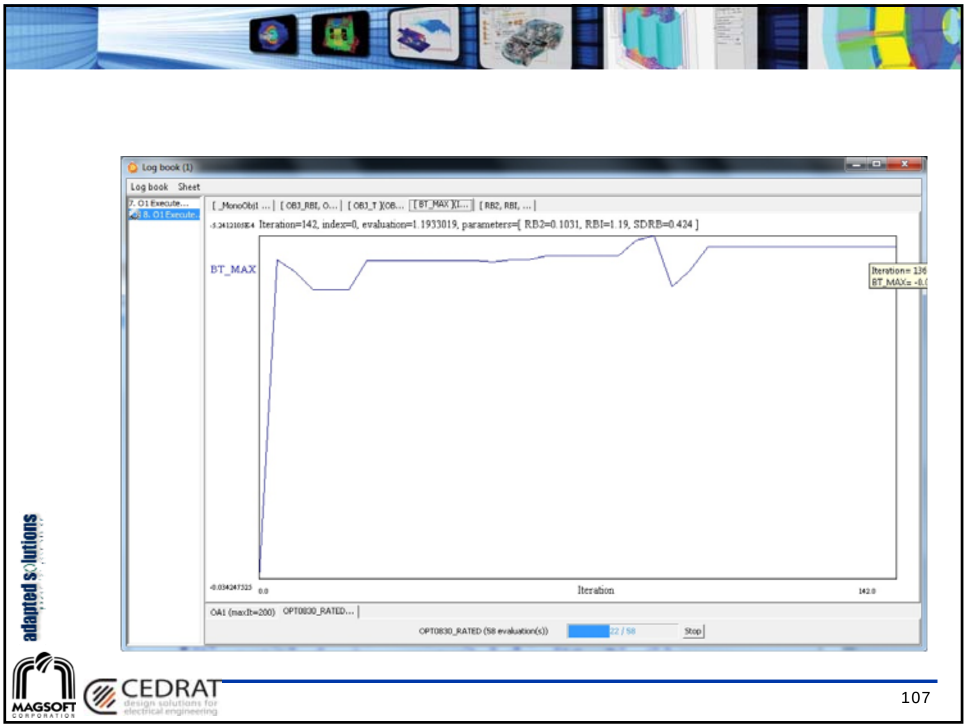
106


Log book (1)
Log book Sheet
7. O1 Execute...
8. O1 Execute
Iteration=142, index=0, evaluation=1.1933019, parameters=[RB2=0.1031, RBI=1.19, SDRB=0.424]
BT_MAX
0.0
Iteration
142.0
OA1 (maxIt=200)
OPT0830_RATED...
OPT0830_RATED (58 evaluation(s))
Stop
adapted solutions
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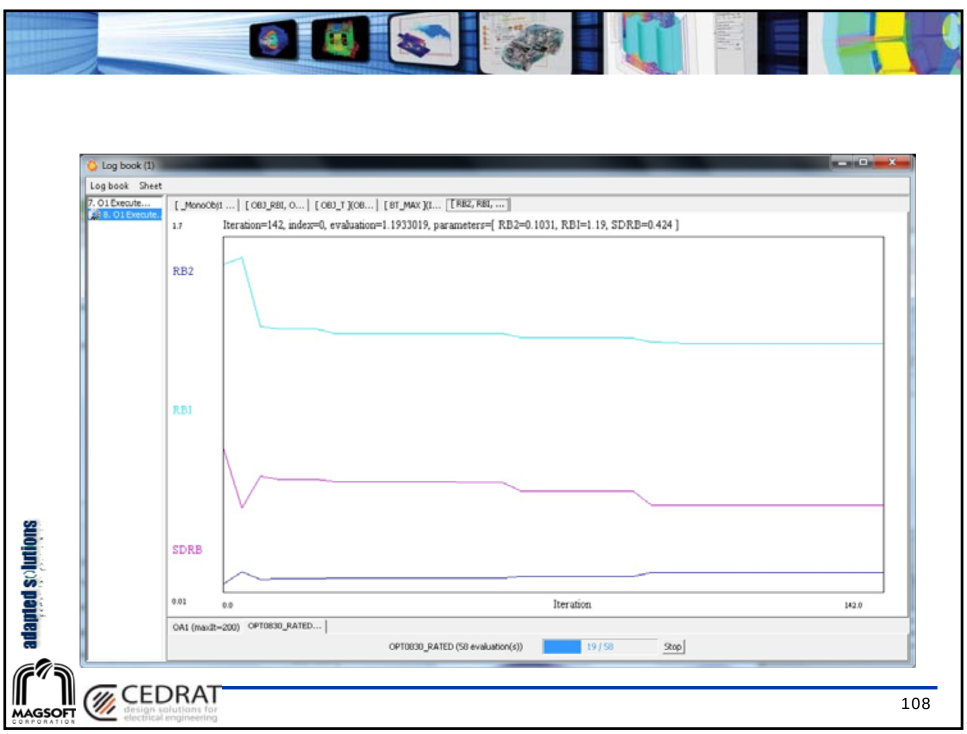
107


Log book (1)
Log book Sheet
7. O1 Execute...
8. O1 Execute
1.7
Iteration=142, index=0, evaluation=1.1933019, parameters=[RB2=0.1031, RBI=1.19, SDRB=0.424]
RB2
RBI
SDRB
0.01
0.0
Iteration
142.0
OA1 (maxIt=200)
OPT0830_RATED...
OPT0830_RATED (58 evaluation(s))
19 / 58
Stop
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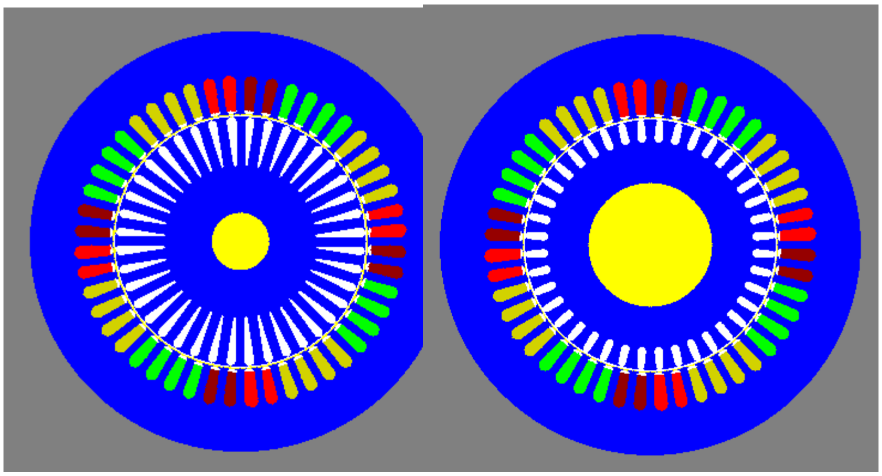
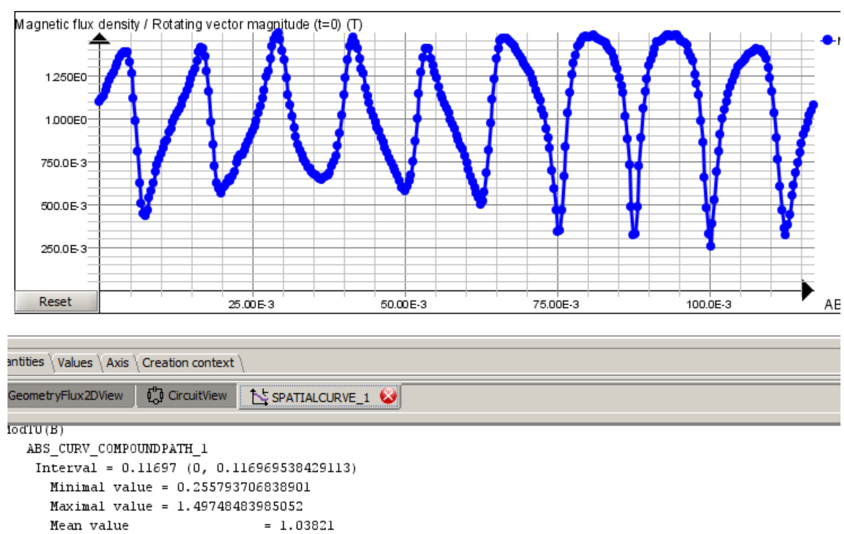
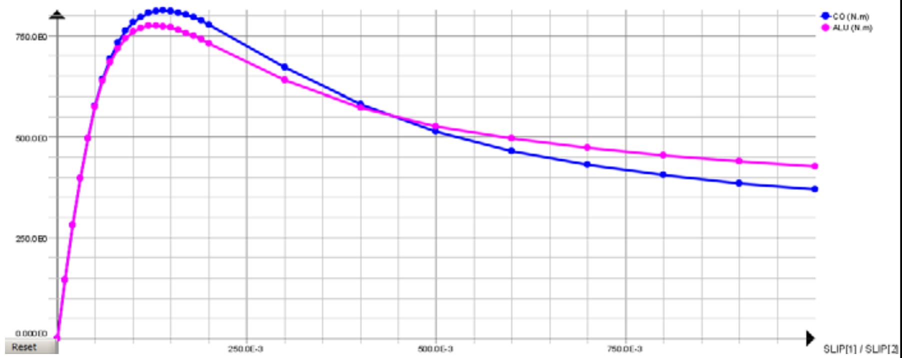
108




Magnetic flux density / Rotating vector magnitude (t=0) (T)
1.250E0
1.000E0
750.0E-3
500.0E-3
250.0E-3
Reset
25.00E-3
50.00E-3
75.00E-3
100.0E-3
AB
antities
Values
Axis
Creation context
GeometryFlux2DView
CircuitView
SPATIALCURVE_1
lodTU(B)
ABS_CURV_COMPOUNDPATH_1
Interval = 0.11697 (0, 0.116969538429113)
Minimal value = 0.255793706838901
Maximal value = 1.49748483985052
Mean value = 1.03821



Co lock rotor torque :370.428 Nm

Alu lock rotor torque : 426.314 Nm

Power balance

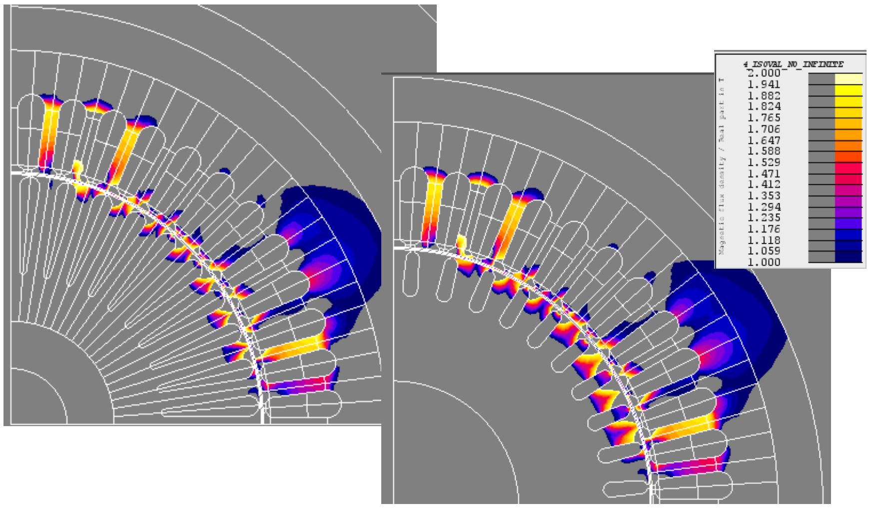
Alu rated slip = 0.0175

input power	-48677.98	speed(rpm)	1768.5
stator loss	1592.90	T (Nm)	**248.581**
rotor loss	**725.86**	Pout	46036.4273
total loss	2494.53	Eff	0.9486
power diff	-147.02	Rotor bar area(mm2) (each)	173.8
diff %	-0.003020297	Rotor iron area(mm2) (1/4)	4446

cop slip = 0.0175

input power	-48661.38	speed(rpm)	1768.5
stator loss	1448.37	T (Nm)	**248.524**
rotor loss	**769.87**	Pout	46025.8711
total loss	2414.33	Eff	0.95015
power diff	-221.19	Rotor bar area(mm2) (each)	73.5
diff %	0.004545396	Rotor iron area(mm2) (1/4)	4232

Flux density between 1 T and 2 T at lock rotor



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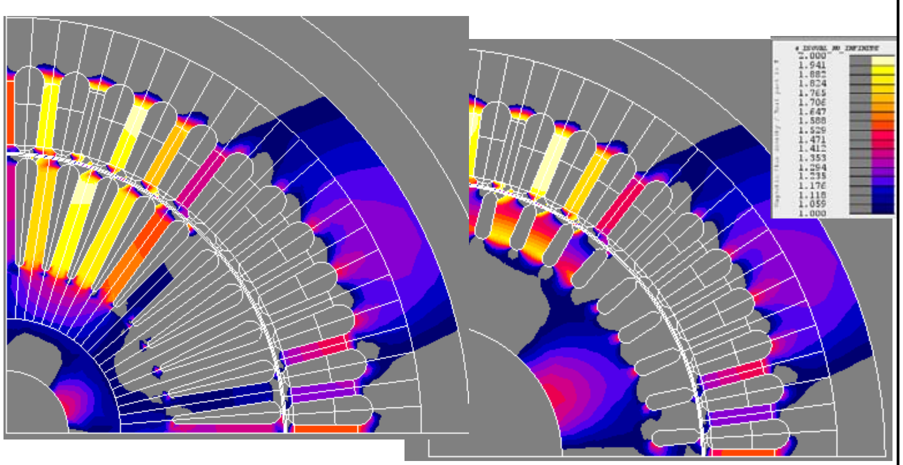
113

Flux density between 1 T and 2 T at rated speed



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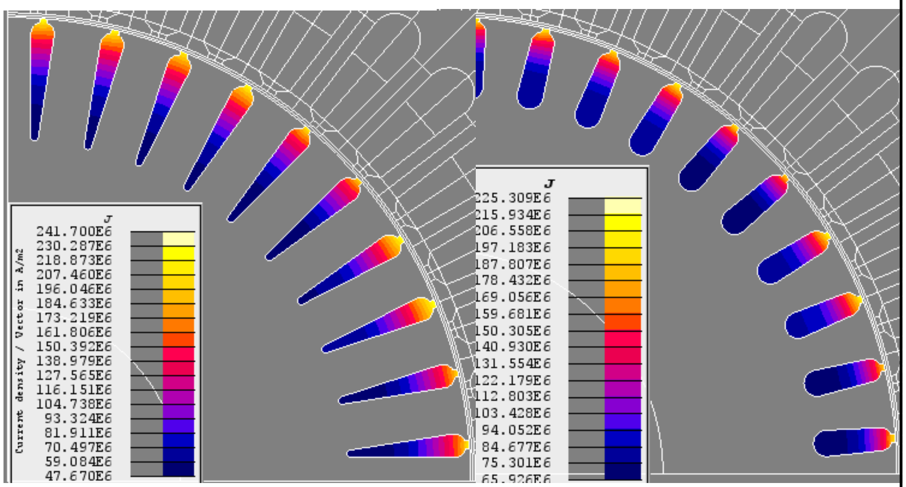
114

Current density at lock rotor



115

Thank you for your interest in our modelling solutions

www.magsoft-flux.com

Philippe.Wendling@magsoft-flux.com
Tan.Pham@magsoft-flux.com
Heide.Lewis@magsoft-flux.com

116