SHAPE OPTIMIZATION FOR ELECTROMAGNETIC DEVICES

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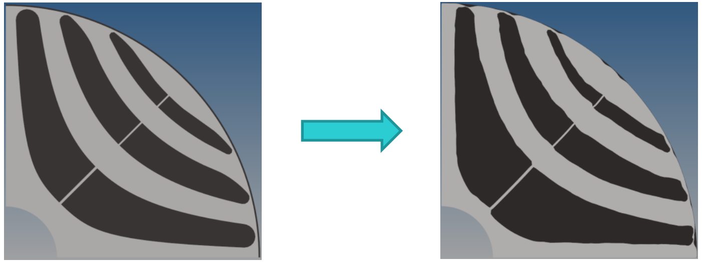
ALTAIR

INTRODUCTION

Introduction

Goal of the tutorial

- The goal of this tutorial is to show how to use the shape optimization feature into Flux
- The purpose of this new feature is to give to you some trends to optimize your device



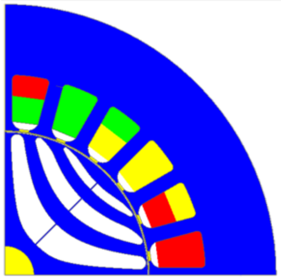
- For more details and reference about the method used please look at the documentation :

Flux ‣ Construction of a Flux project ‣ Structural optimization in Flux ‣ Shape Optimization

Introduction

Studied cases

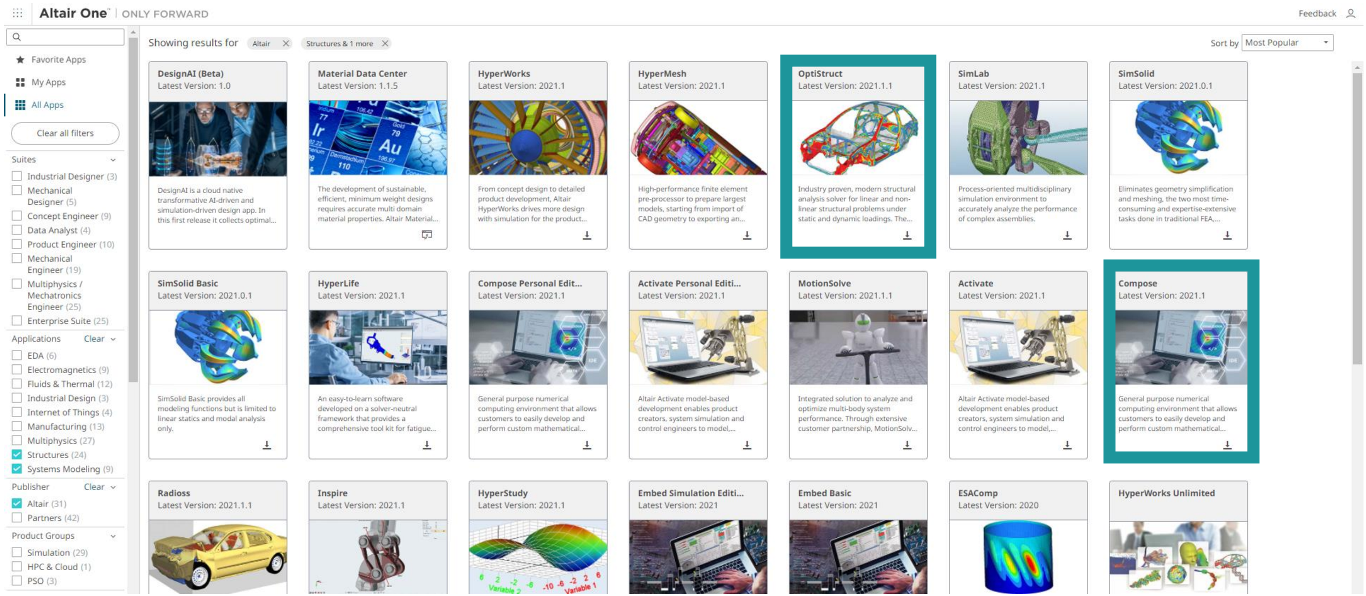
- The example carries out the shape optimization of a synchronous reluctance machine (SRM). Mean torque, calculated using an Altair Compose code, will be optimized.



- **Case 1**: Shape optimization of the mean torque using optimization function programmed in Altair Compose file. No optimization constrains are applied.
- **Case 2**: A similar shape optimization of the torque will be carried out. In this case a rotor mass reduction > 20% will be imposed.
- **Case 3**: Shape optimization of the torque fulfilling two constrains: Rotor symmetry and a reduction mass of the rotor > 20%.

Environment preparation

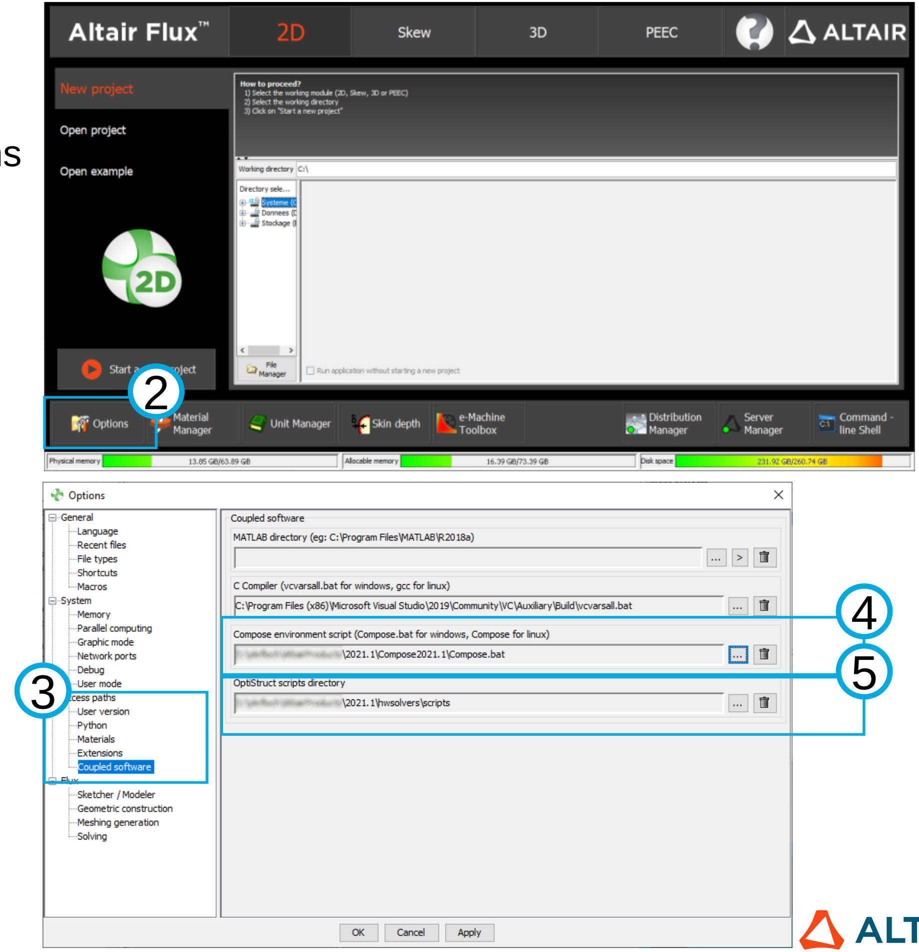
- You need to install on your machine (Available on Altair One Market Place) :
  - Altair OptiStruct 2021.1 (at least)
  - Altair Compose 2021.1 (at least)



Environment preparation

- Set the path into Flux Supervisor Options (Coupled software) for :
  - Altair OptiStruct
  - Altair Compose

Step	Action
1	Open Flux supervisor
2	Open Options
3	Select [Access path] -> [Coupled software]
4	Establish Compose environment script
5	Indicate OptiStruct scripts directory



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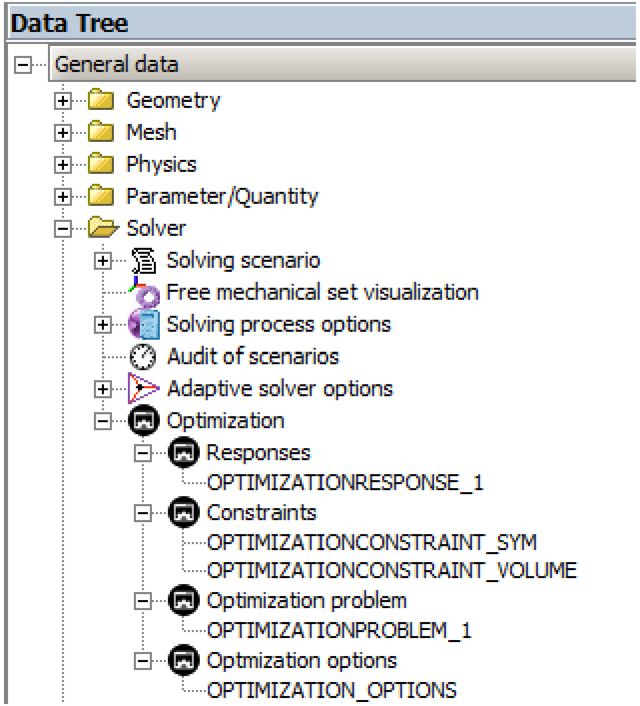
SHAPE OPTIMIZATION WITH ALTAIR FLUX

Shape Optimization with Altair Flux

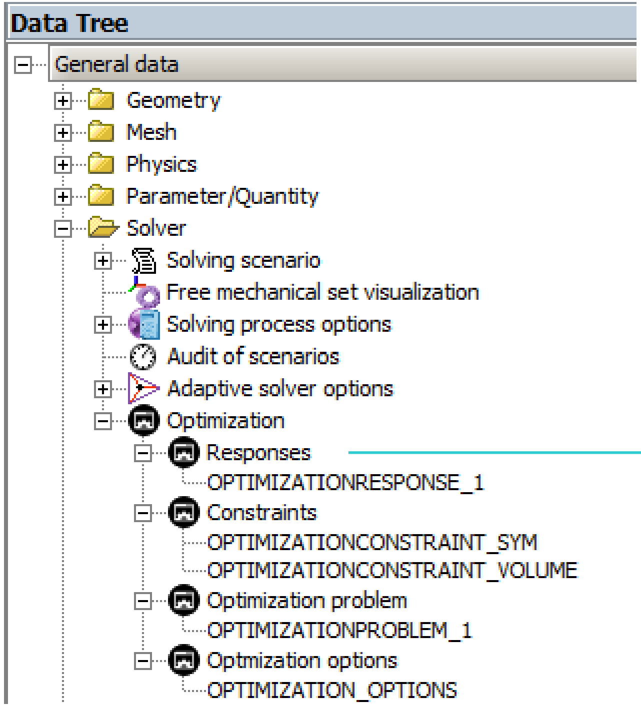
Implemented for multiple applications

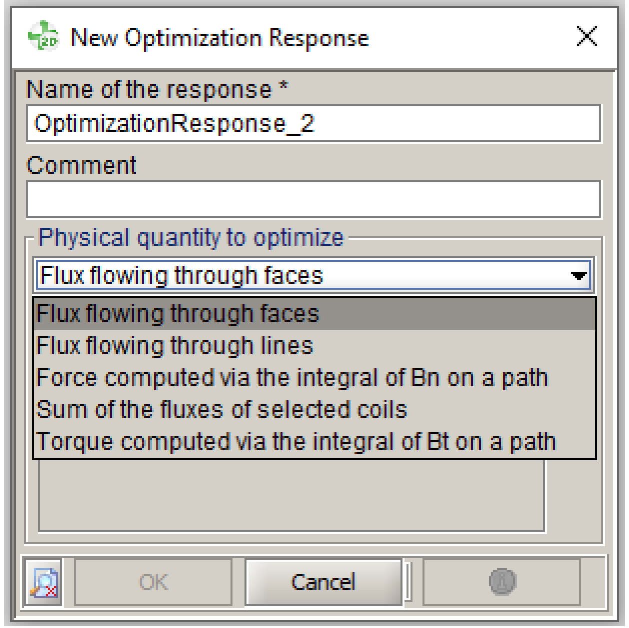


- **2D applications**
  - **Magnetostatic**
  - **Transient Magnetic**
- Linear and Non-Linear Material
- Parametric study (without remeshing)
- Magnets allowed (no change of the orientation)
- **Multiple Responses**
  - Sum of Flux trough the coils
  - Flux trough a list of faces / list of lines
  - Torque
  - Magnetic forces
- **Constraints allowed**
  - Volume of a part of the device
  - Symmetries

Shape Optimization with Altair Flux

Define the output variable





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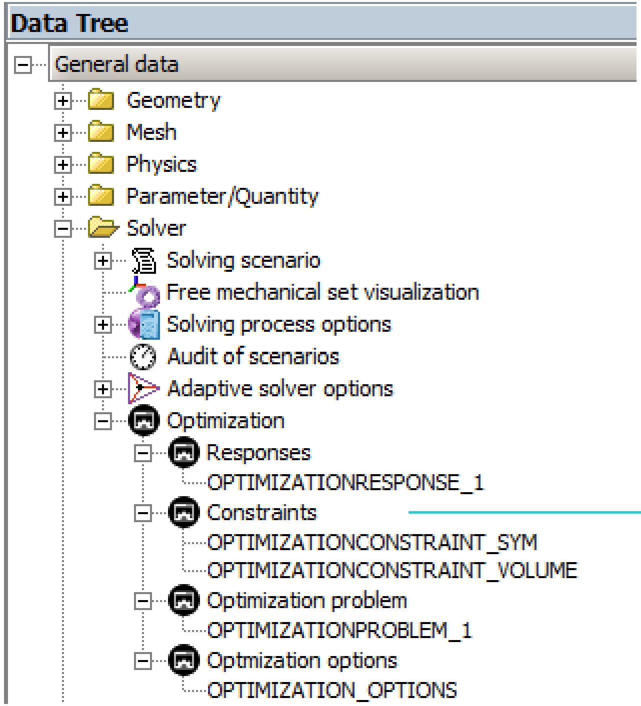
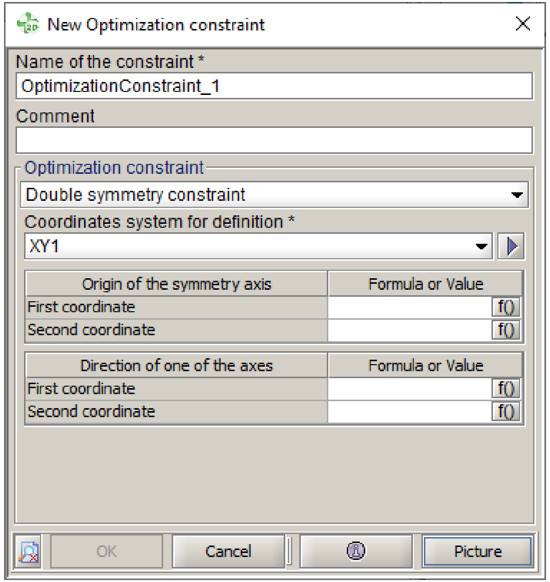
Shape Optimization with Altair Flux

Define the optimization problem





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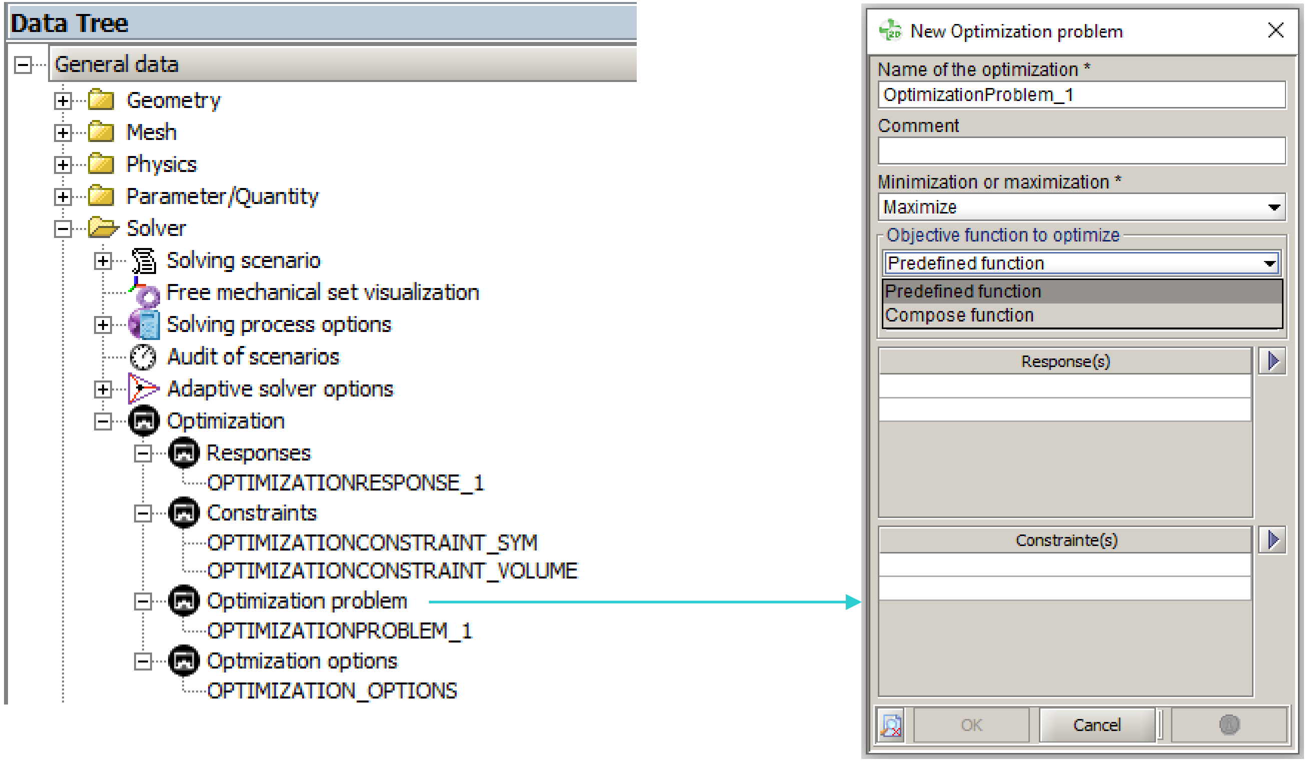
Shape Optimization with Altair Flux

Define the optimization problem



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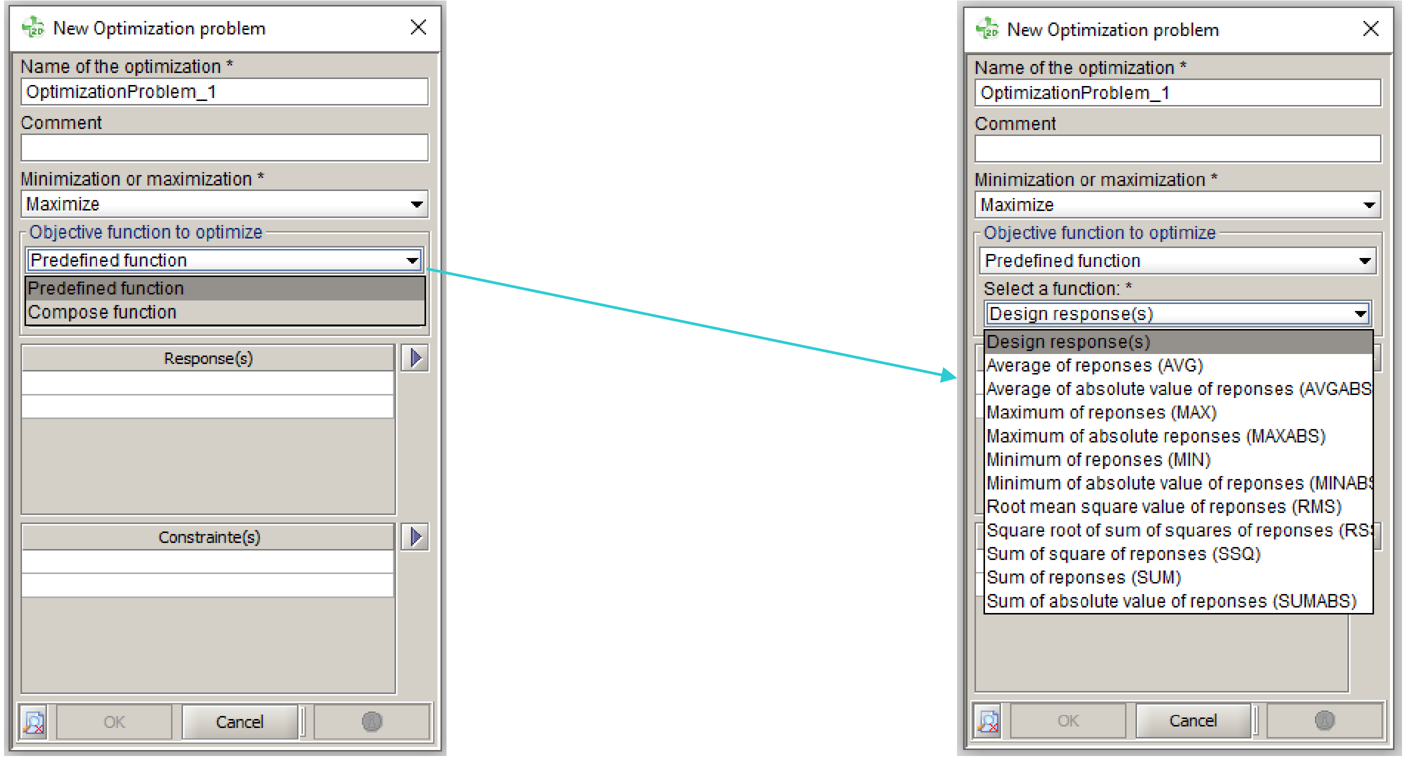
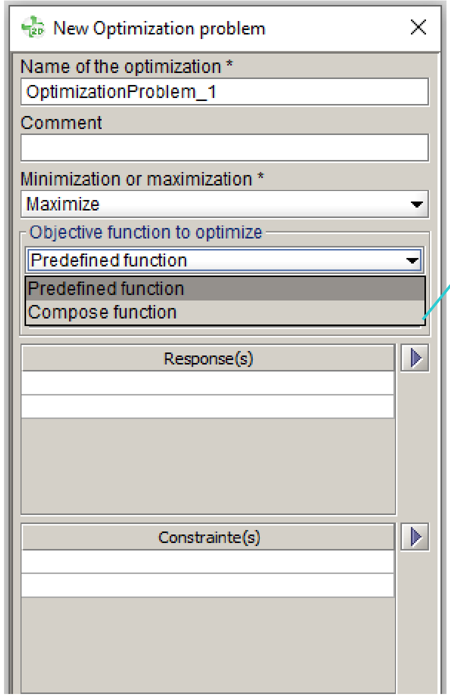
Shape Optimization with Altair Flux

Define the optimization problem – Predefined function



Shape Optimization with Altair Flux

Define the optimization problem – User function (through Compose)




```
function [rresp, dresp, udata] = Obj_Func (iparam, rparam, nparam, iresp, rresp, dresp, nresp, isens, udata)
    %scenario/project values
    Angpos=[2:2:180]; %Rotor angular position (for currents)
    n=[0:44,-45:-1]; %fft index for 90 samples in one period
    P=2; %Number of pole pairs
    c_angle=45; %Control angle (°)
    Ipk=15; %Peak current (Apk)
    %Read flux in phase 1 from flux project and build flux in phase 2 and 3 from it
    flux = rparam;
    ph1=[flux(2:end),-flux(3:end-1)];
    PH1=fft(ph1);
    PH2=PH1.*exp(-j*2*pi/3*n);
    PH3=PH1.*exp(j*2*pi/3*n);
    ph2=ifft(PH2);
    ph3=ifft(PH3);

    %Rebuild currents that are fed in Flux project
    I1= Ipk*sin(pi/180*(Angpos*P+c_angle));         %Current in phase 1
    I2= Ipk*sin(pi/180*(Angpos*P+c_angle)-2*pi/3);  %Current in phase 2
    I3= Ipk*sin(pi/180*(Angpos*P+c_angle)+2*pi/3);  %Current in phase 3
    save('auxiliar.mat','flux')
    %Output (torque's mean value over one period)
    T = P/sqrt(3)*(I1.*(ph3-ph2)+I2.*(ph1-ph3)+I3.*(ph2-ph1));
    rresp(1) = mean(T);
end
```

Motor's torque through Park's equation

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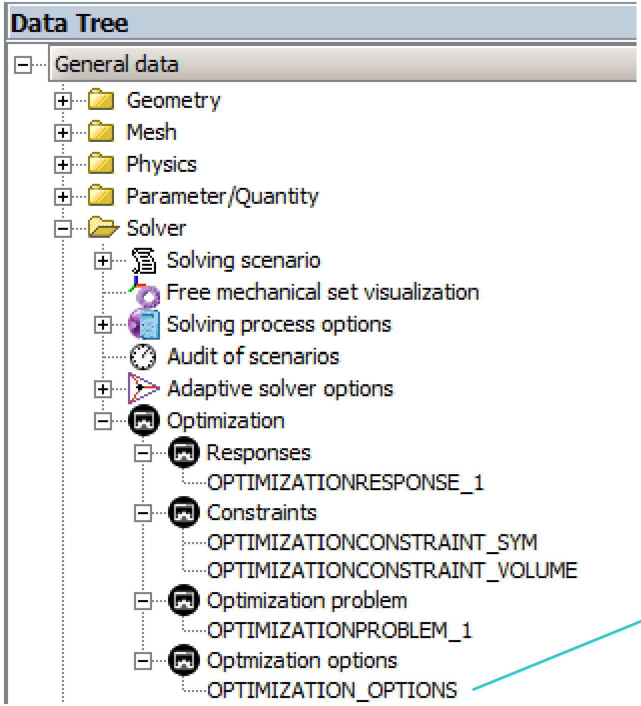
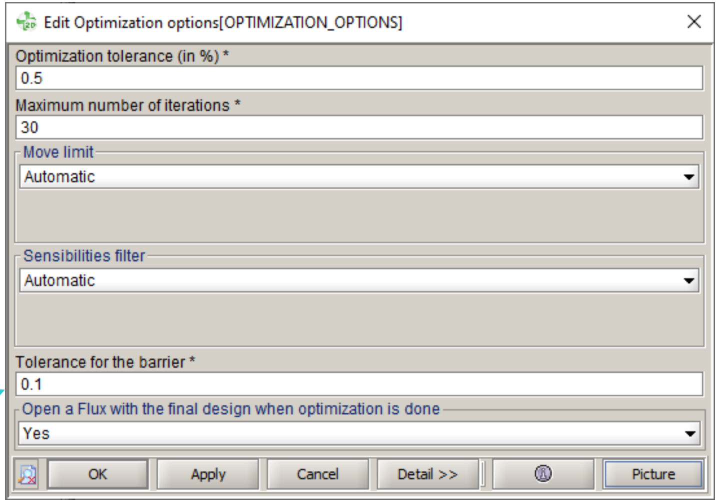
Shape Optimization with Altair Flux

Define the optimization problem





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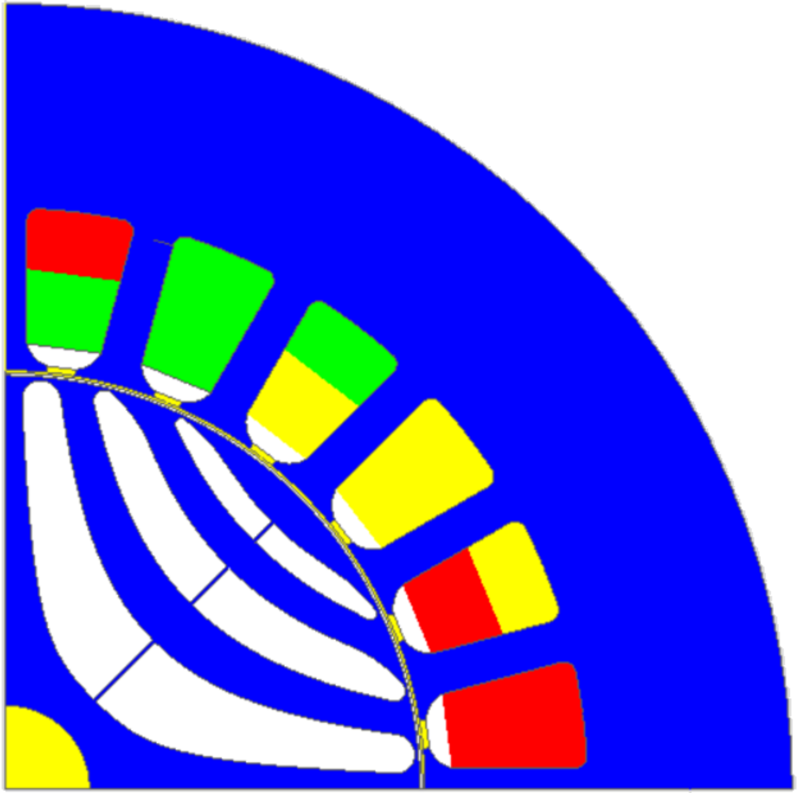
TUTORIAL - SHAPE OPTIMIZATION OF SYNCHRONOUS RELUCTANCE MACHINE (SRM)

INTRODUCTION

Synchronous Reluctance Machine Optimization

SRM as ideal candidate for shape optimization



- **Why SRM?**
  - **Very few constrains** needed
  - Only **two materials** in the rotor: Iron and air
  - **Reluctance** is causing all the effective torque: Shape optimization acts over it directly
  - At constant speed: torque **-> mechanical power -> power density**

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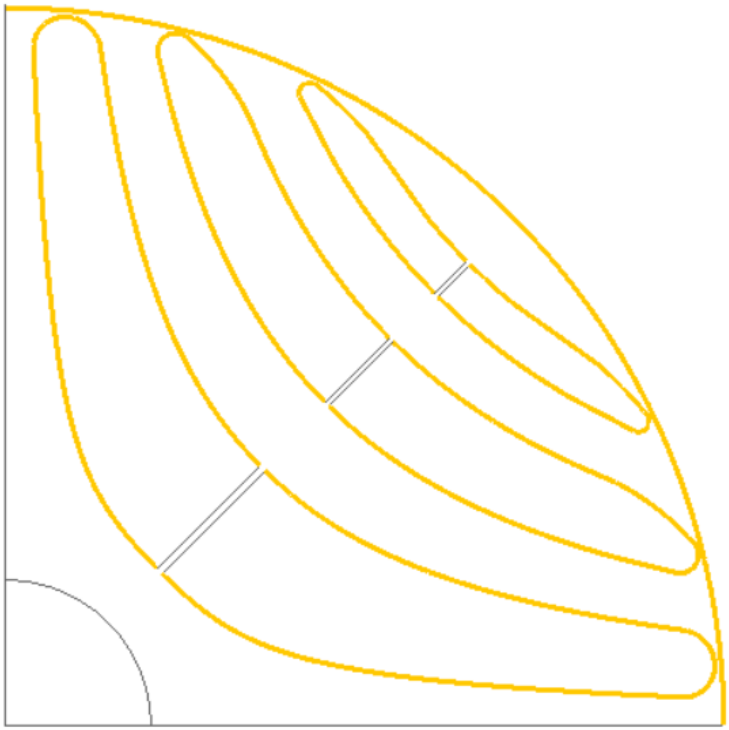
Synchronous Reluctance Machine Optimization

Optimization inputs

- Rotor airgap interphase + rotor holes
- Goal function : Torque according with park equation:

$$T = \frac{P}{\sqrt{3}}\left(I_1(\phi_3 - \phi_2) + I_2(\phi_1 - \phi_3) + I_3(\phi_2 - \phi_1)\right)$$

- Three different optimizations have been carried out depending on restriction
  1. Basic optimization (no restrictions)
  2. Rotor mass reduction ≥ 20% imposed
  3. Symmetry and rotor mass reduction imposed

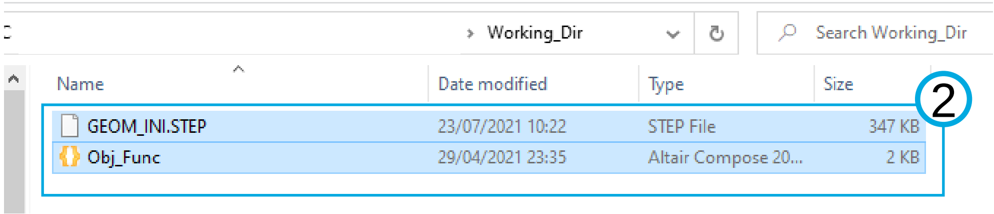


STEP BY STEP TUTORIAL – GEOMETRY AND MESH

Flux project preparation

- Copy initial files from example directory into working directory

Step	Action
1	Open directory of the example “Shape optimization of a SRM”
2	Copy the input files *GEOM_INI.STEP* and *Obj_Func.OML* in the working directory



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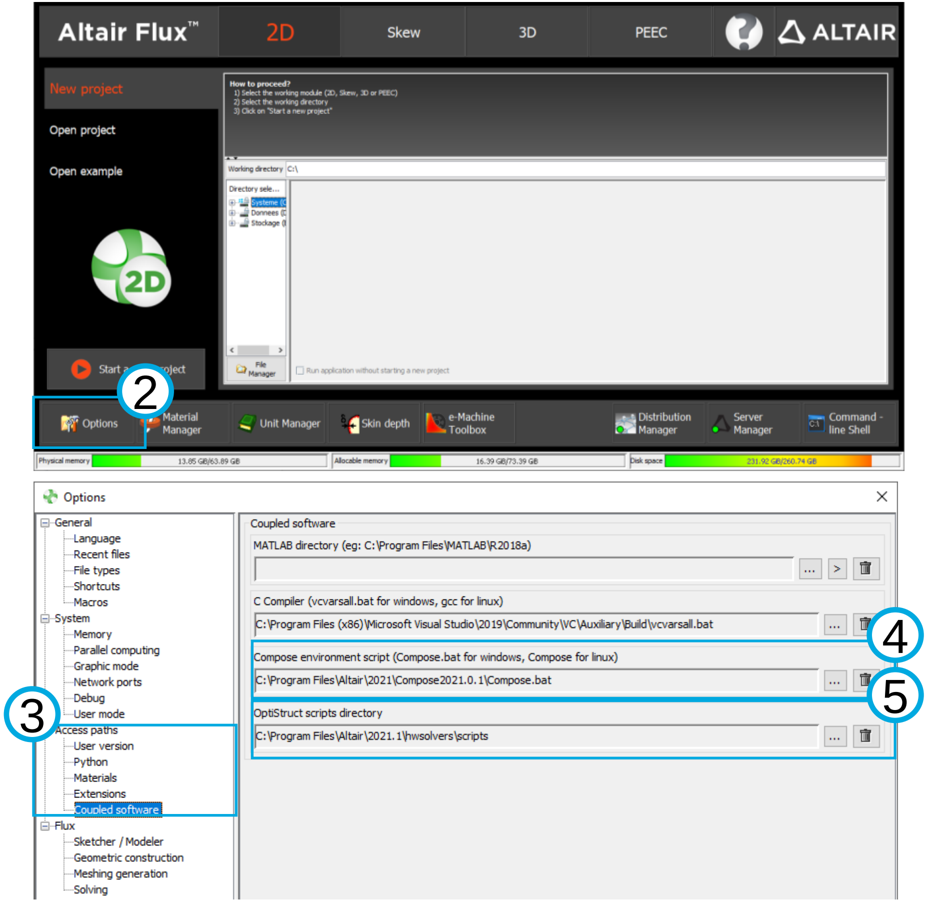
Flux project preparation

- Define Altair OptiStruct and Altair Compose paths for coupling

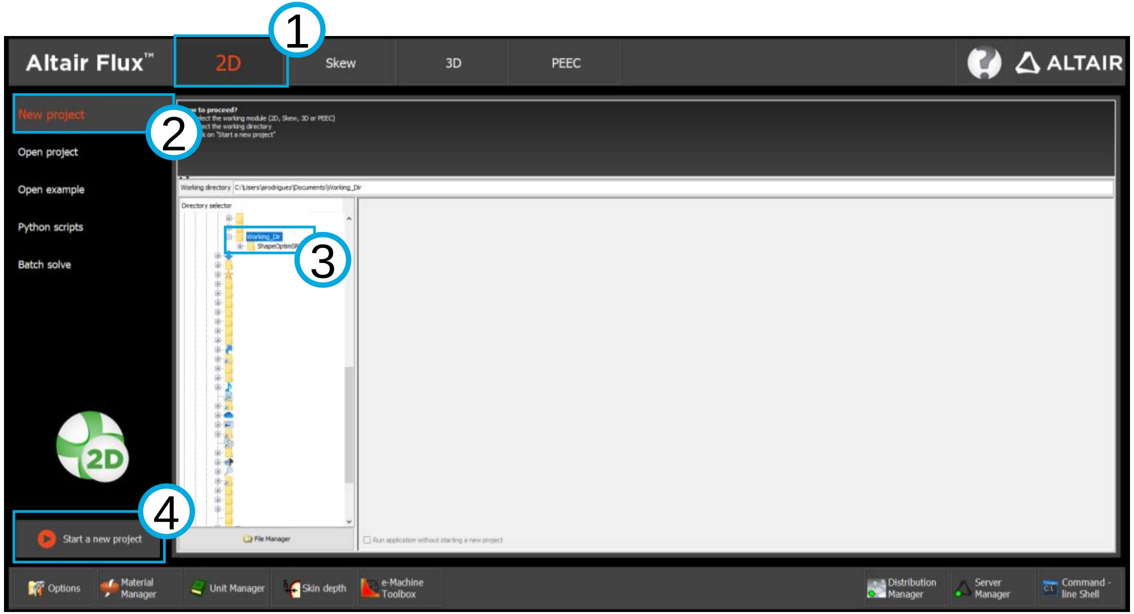
Step	Action
1	Open Flux supervisor
2	Open Options
3	Select [Access path] -> [Coupled software]
4	Establish Compose environment script
5	Indicate OptiStruct scripts directory



Flux project preparation

- Launch new Flux 2D project

Step	Action
1	Select the [2D] simulation context
2	Click on [New project]
3	Choose the working directory
4	Click on [Star a new project]



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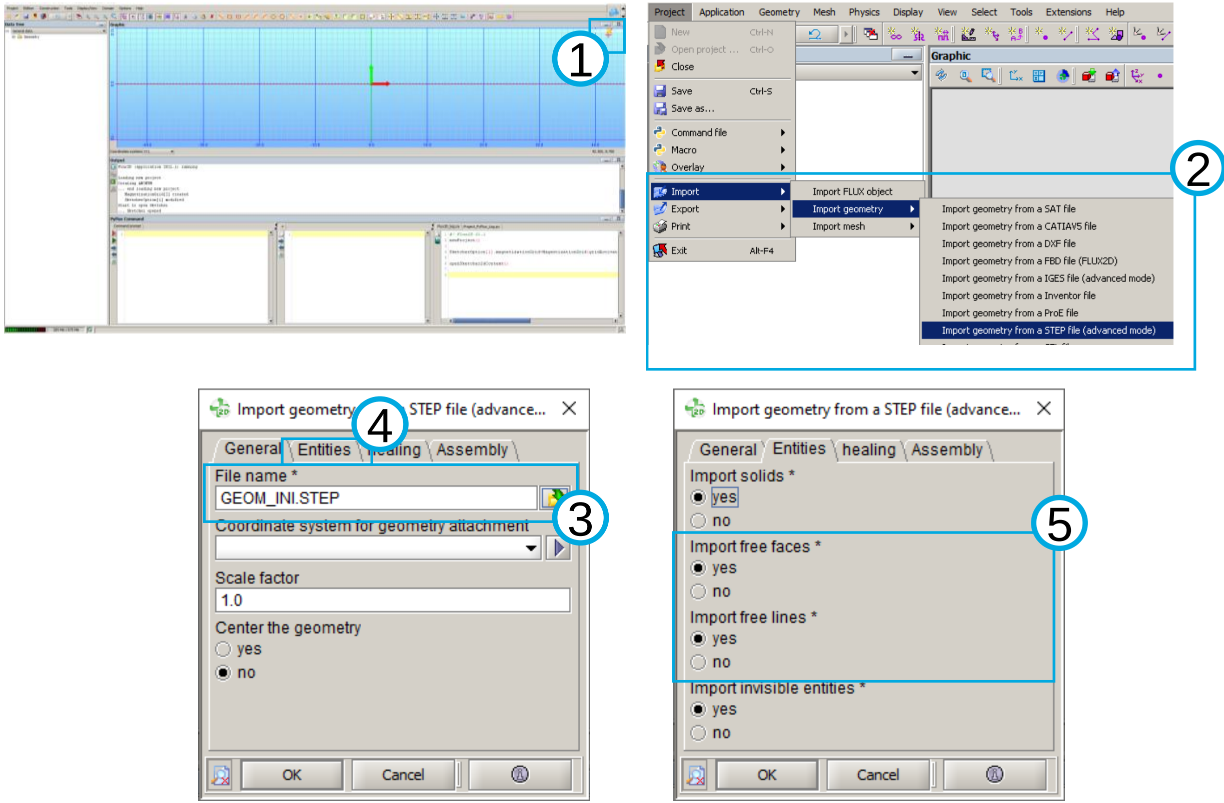
Geometry

- Import SRM geometry

Step	Action
1	Close the sketcher
2	Click on menu [Project] -> [Import] -> [Import geometry] -> [Import geometry from a STEP file (advanced mode)]
3	Choose *GEOM_INI.STEP* as input file
4	Go to tab [Entities]
5	Check options [Import free faces], [Import free lines]



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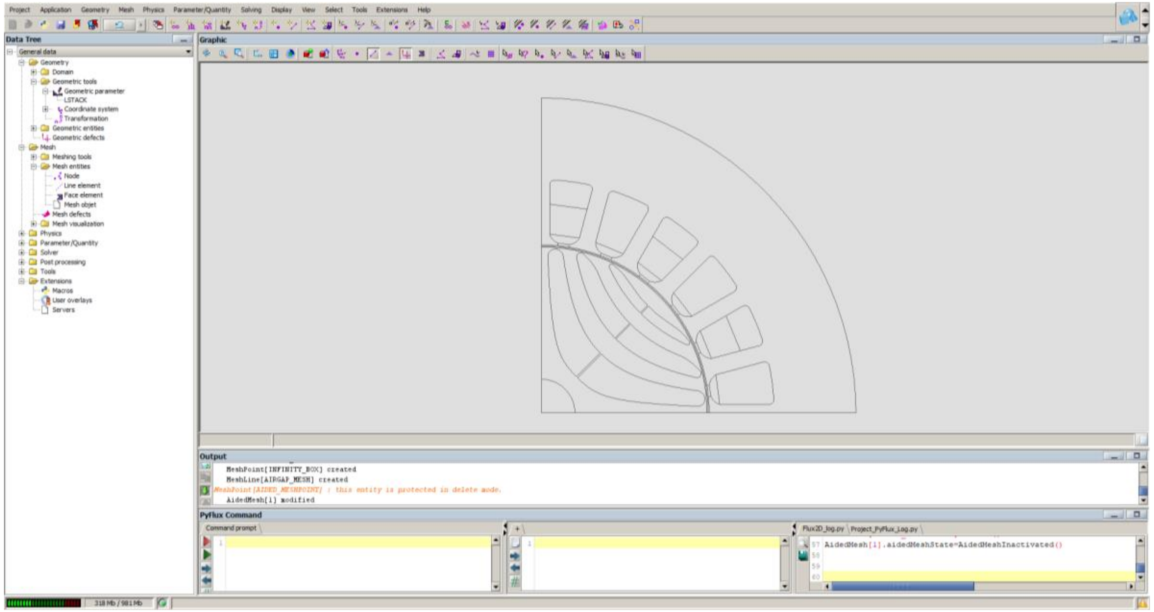
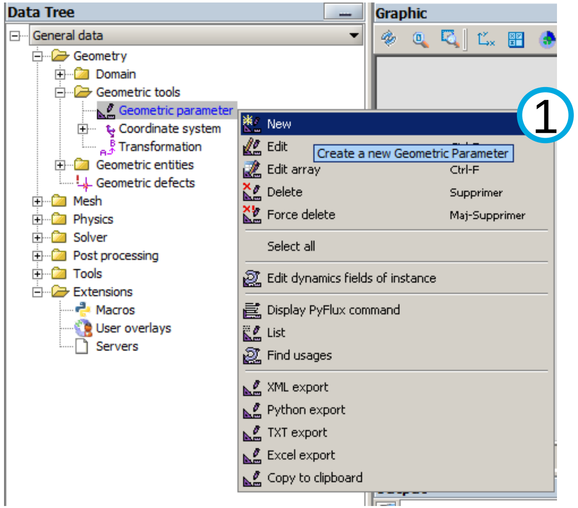
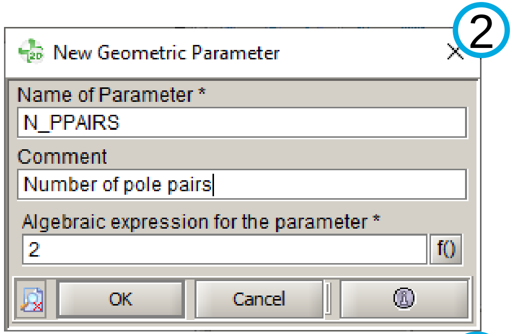


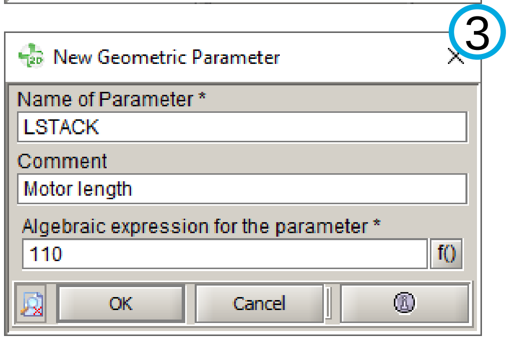
Geometry

- Define geometric parameters

Step	Action
1	Go to [Data Tree] -> [Geometry] ->[Geometric tools] -> [Geometric parameter] -> [New]
2	Define a geometric parameter N_PPAIRS =2 (number of pole pairs)
3	Define a geometric parameter LSTACK = 110 (motor length)







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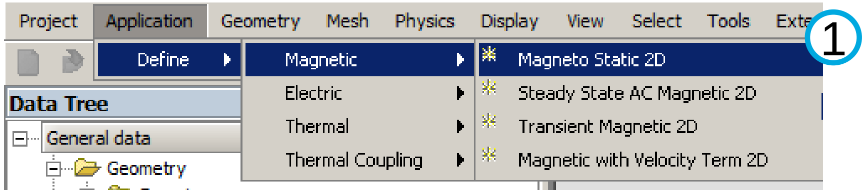
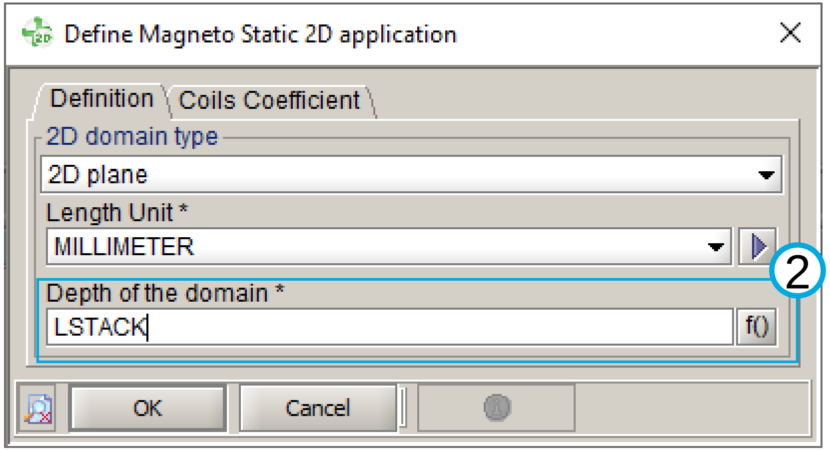
Physics domain

- Define physical application

Step	Action
1	Click on menu [Application] -> [Define] -> [Magnetic] -> [Magneto Static 2D]
2	Stablish the depth of the domain = LSTACK





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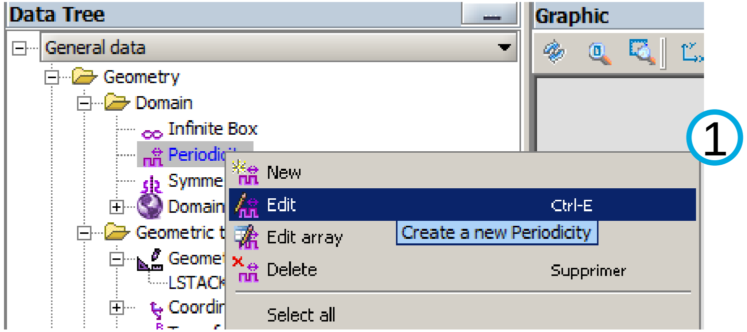
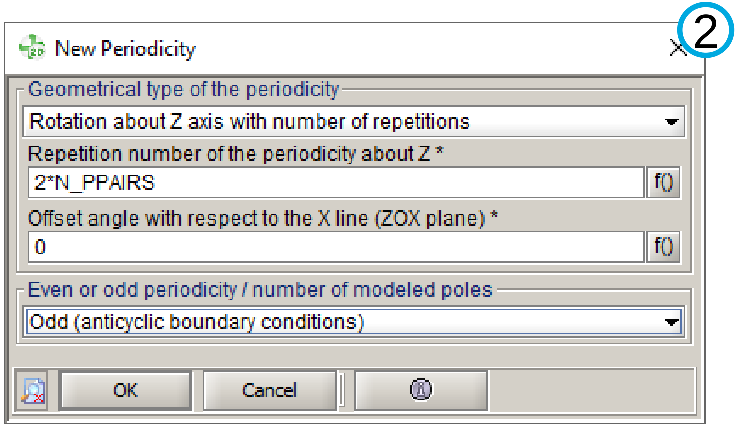
Physics domain

- Define motor's periodicity

Step	Action
1	Go to [Data Tree] -> [Geometry] -> [Domain] -> [Periodicity] ->[New]
2	Define new periodicity: 2*N_PPAIRS repetition, and odd periodicity





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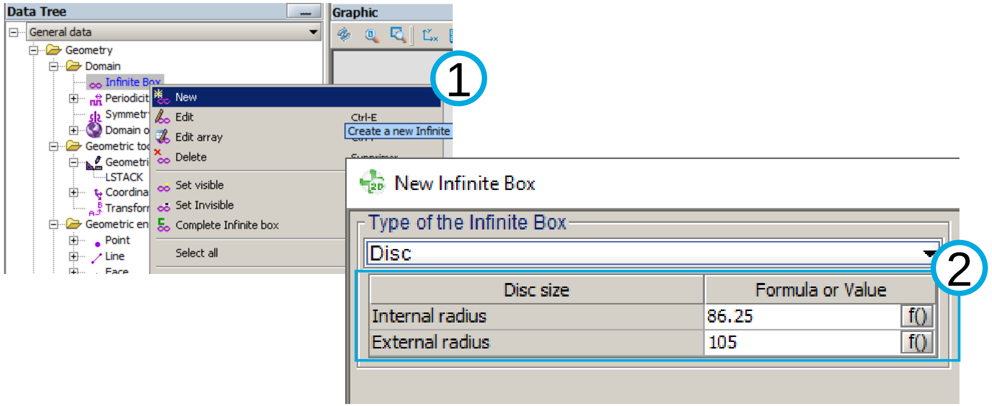
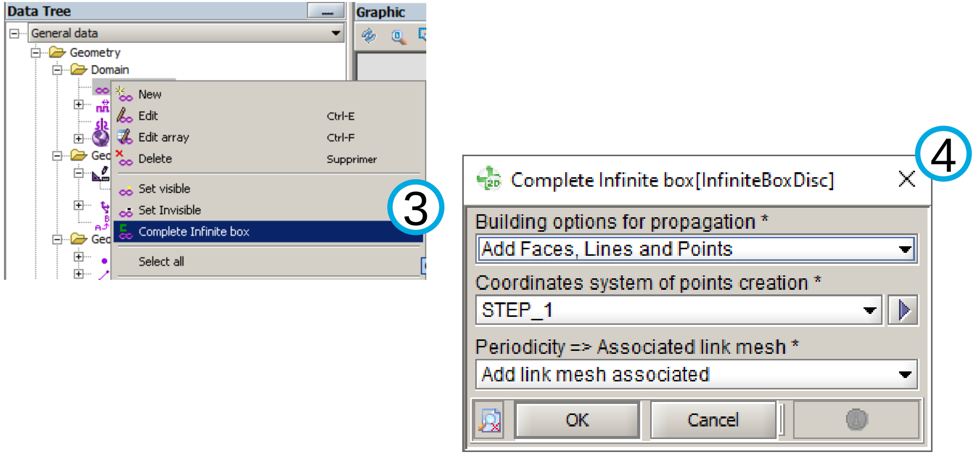
Physics domain

- Add infinite box

Step	Action
1	Go to [Data Tree] -> [Geometry] -> [Domain] -> [Infinite box] ->[New]
2	Create infinity box with given internal and external radius
3	Go to [Data Tree] -> [Geometry] -> [Domain] -> [Infinite box] ->[Complete Infinite box]
4	Accept default options and complete infinite box





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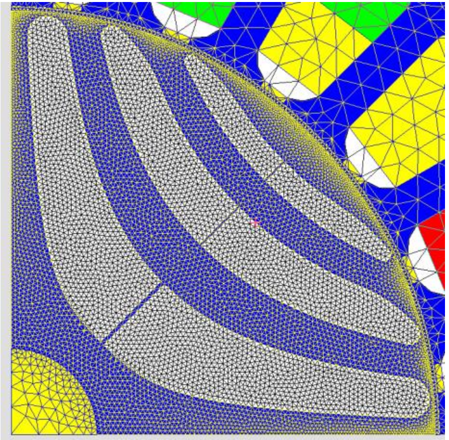
Meshing

- The goal of this part is to create a mesh suitable for shape optimization

The mesh should be, as much as possible,
regular in the area that touches the lines that we want to optimize



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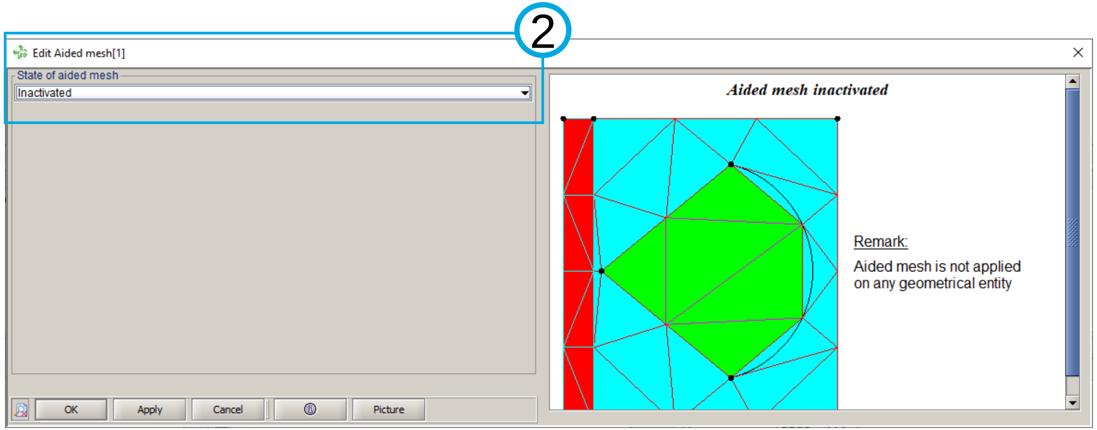
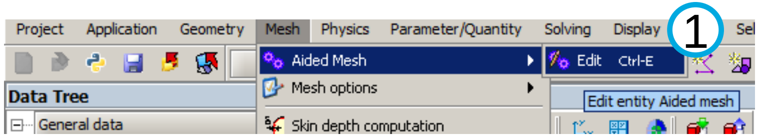
Meshing

- Inactivate aided mesh

Step	Action
1	Go to menu [Mesh] -> [Aided Mesh] -> [Edit]
2	Select Inactivated as state of aided mesh



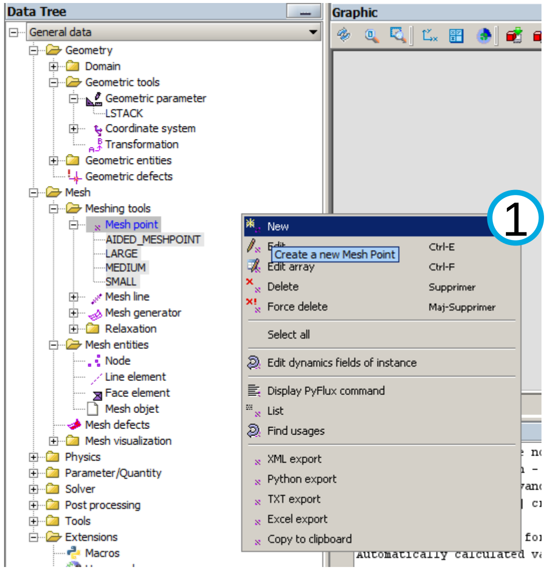


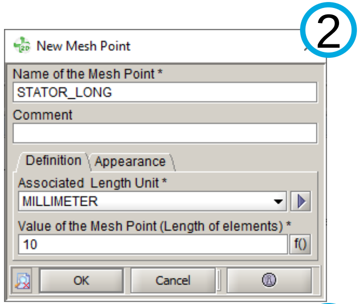
Meshing

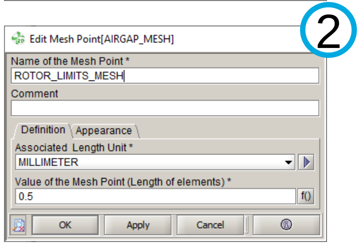
- Define new mesh points

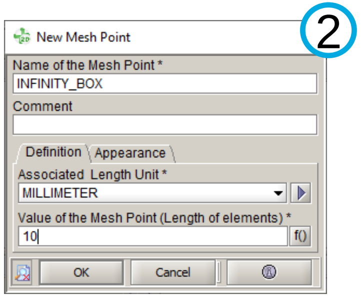
Step	Action
1	Go to [Data Tree] -> [Mesh] -> [Meshing tools] -> [Mesh point] ->[New]
2	Define three new mesh points as indicated in the table below

Point name	Value of the mesh point
STATOR_LONG	10
ROTOR_LIMITS_MESH	0.5
INFINITY_BOX	10









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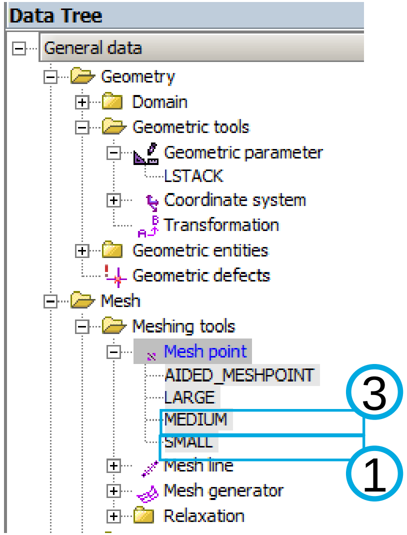
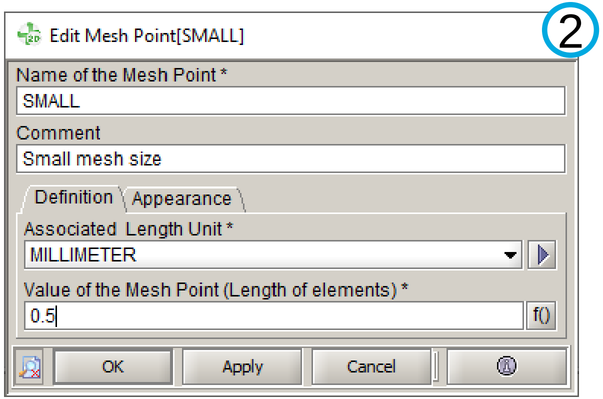
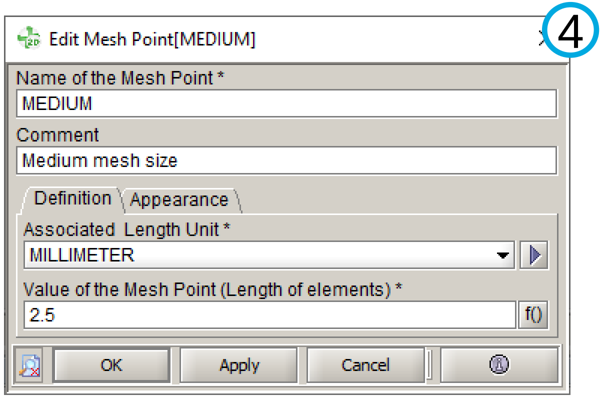
Meshing

- Update mesh points values

Step	Action
1	Go to [Data Tree] -> [Mesh] -> [Meshing tools] -> [SMALL]->[Edit]
2	Assign 0.5 as value of the mesh point
3	Go to [Data Tree] -> [Mesh] -> [Meshing tools] -> [MEDIUM] ->[Edit]
4	Assign 2.5 as value of the mesh point







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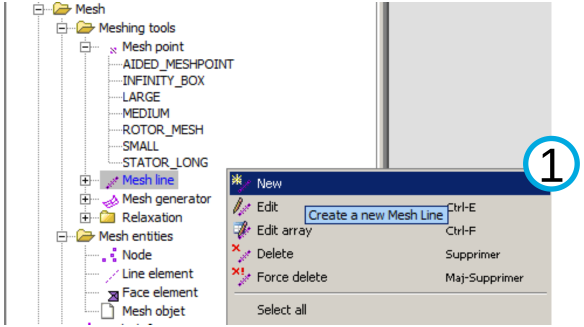
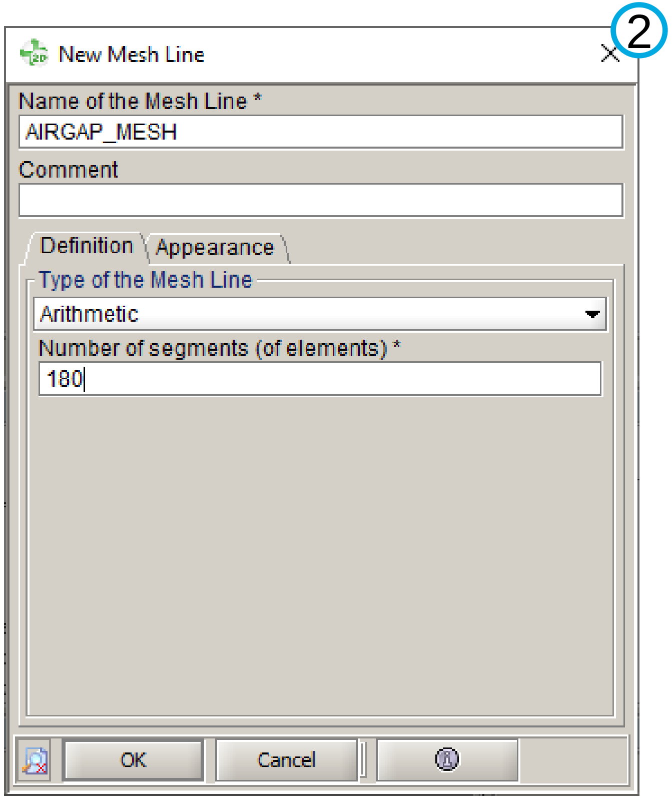
Meshing

- Define new mesh line

Step	Action
1	Go to [Data Tree] -> [Mesh] -> [Meshing tools] -> [Mesh line] ->[New]
2	Define new mesh line AIRGAP_MESH as shown in the figure





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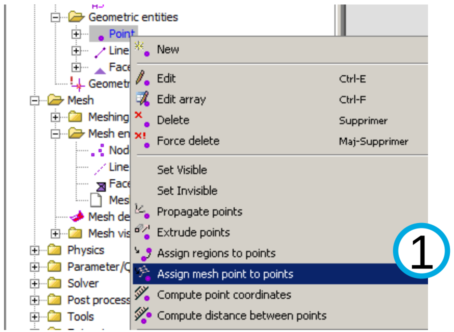
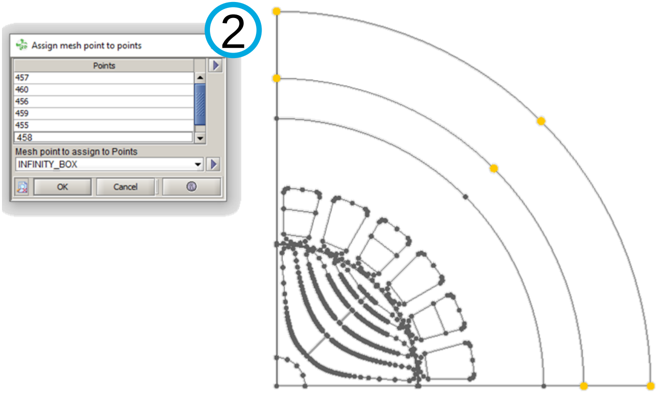
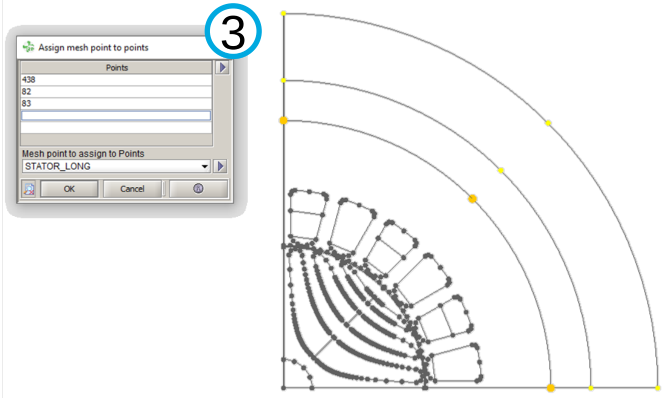
Meshing

- Assign mesh points to points

Step	Action
1	Go to [Data Tree] -> [Geometric] -> [Geometric entities] -> [Point] ->[Assign mesh points to points]
2	Assign "INFINITY_BOX" to infinite box points as shown in the figure
3	Assign "STATOR_LONG" to external stator points as shown in the figure







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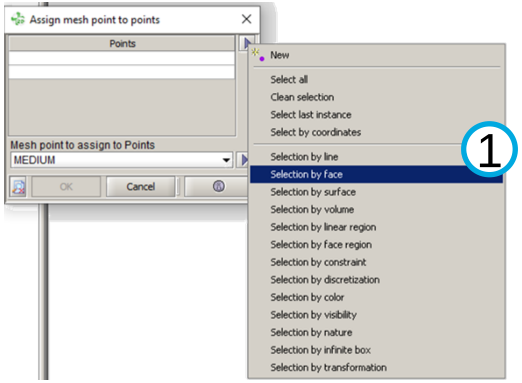
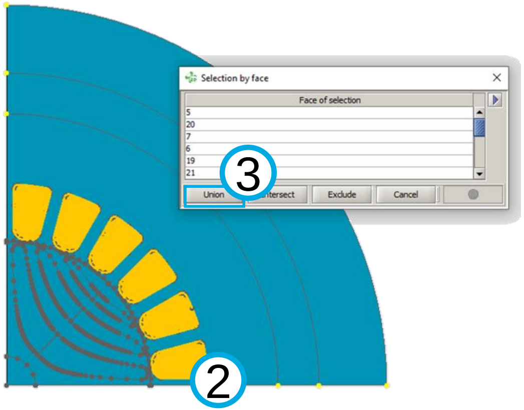
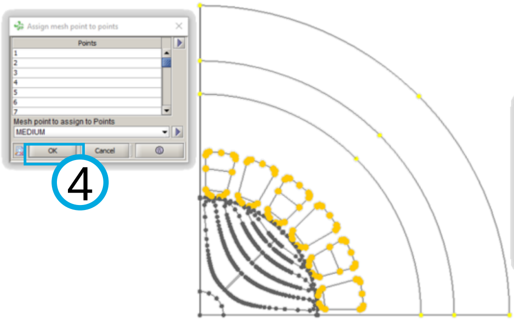
Meshing

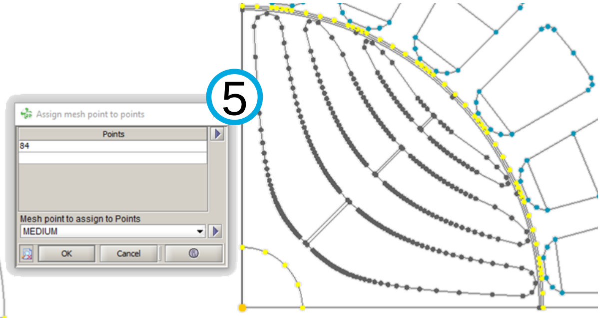
- Assign mesh points to points

Step	Action
1	To assign MEDIUM mesh points, select the points through “selection by face” option
2	Select the faces corresponding to the slots
3	Choose “Union option”
4	Click ok to accept selection
5	Assign also the central point in the origin to MEDIUM mesh point









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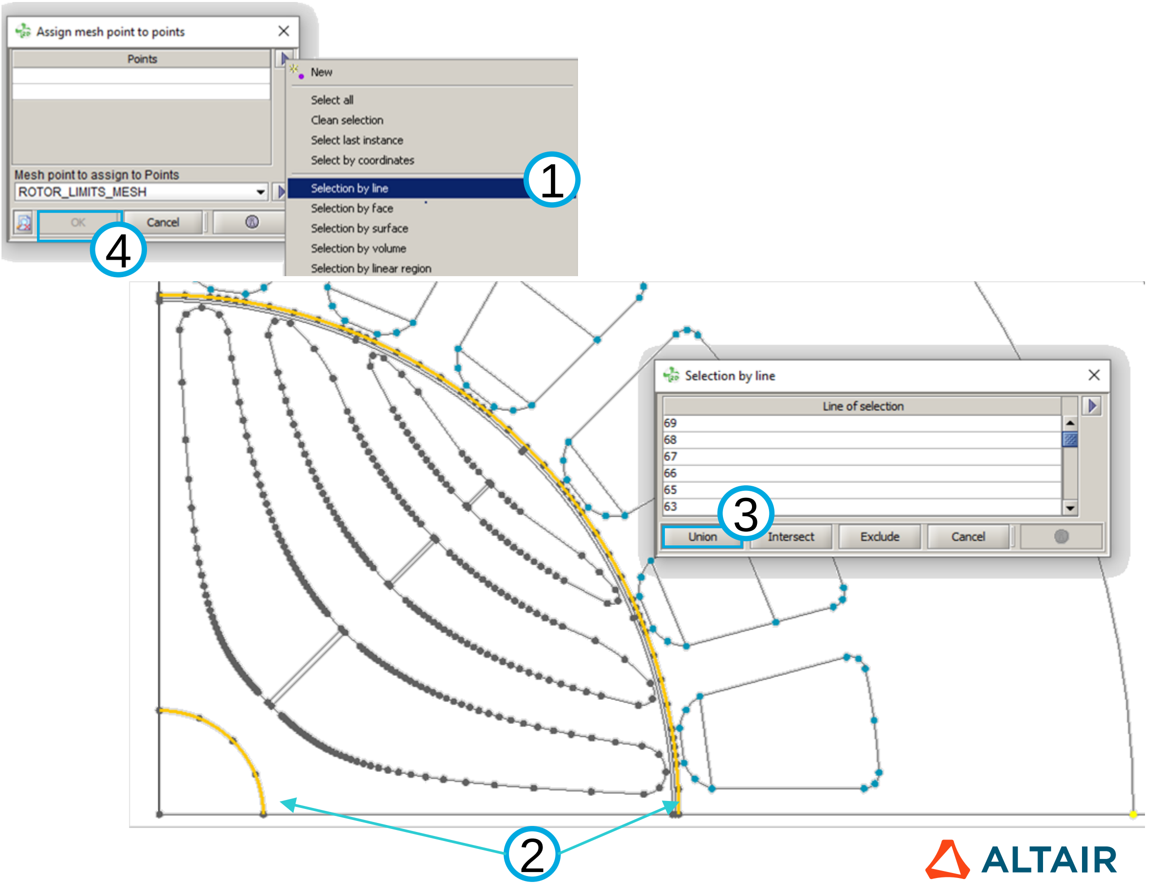
Meshing

- Assign mesh points to points

Step	Action
1	To assign ROTOR_LIMITS_MESH mesh points, select the points through "selection by line" option
2	Select the lines corresponding to the shaft-rotor limits and the stator-airgap limits
3	Choose "Union option"
4	Click ok to accept selection



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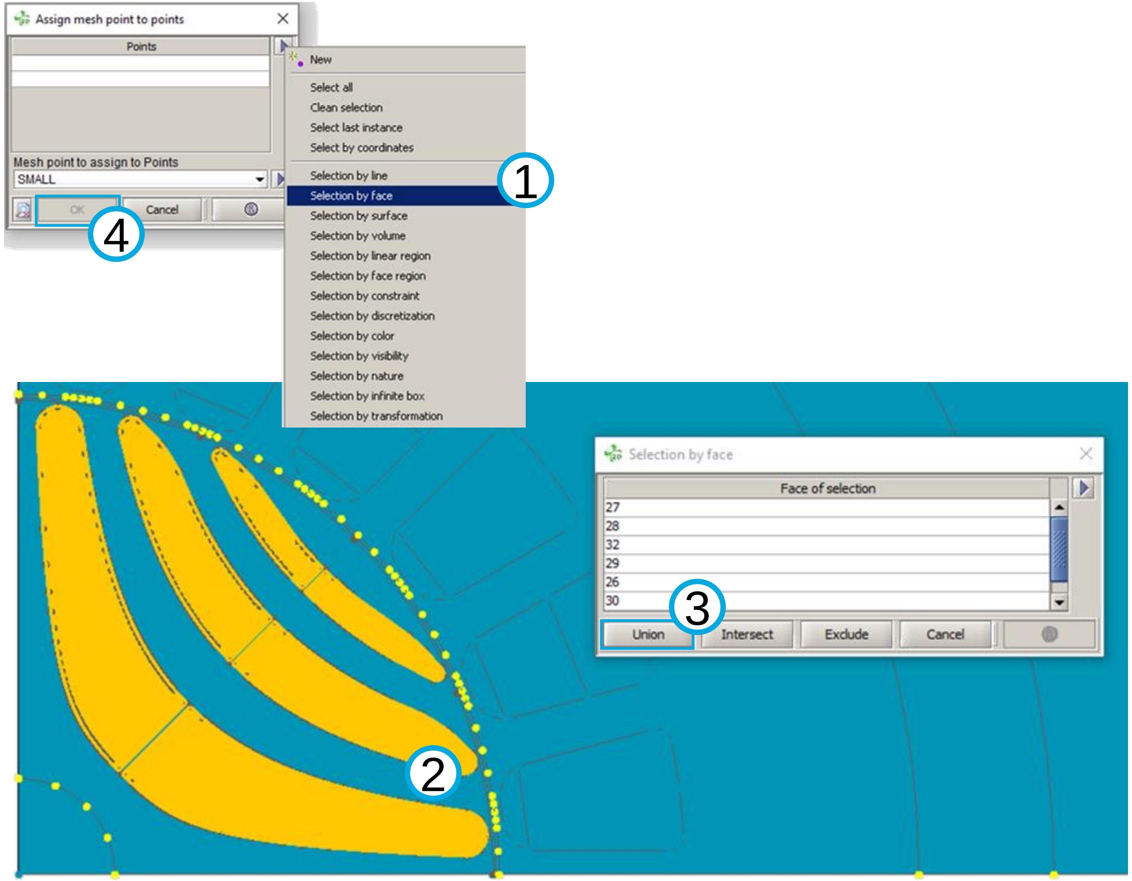
Meshing

- Assign mesh points to points

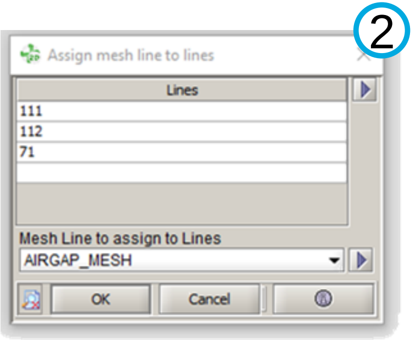
Step	Action
1	To assign SMALL mesh points, select the points through "selection by face" option
2	Select the faces corresponding to the rotor's air holes
3	Choose "Union option"
4	Click ok to accept selection

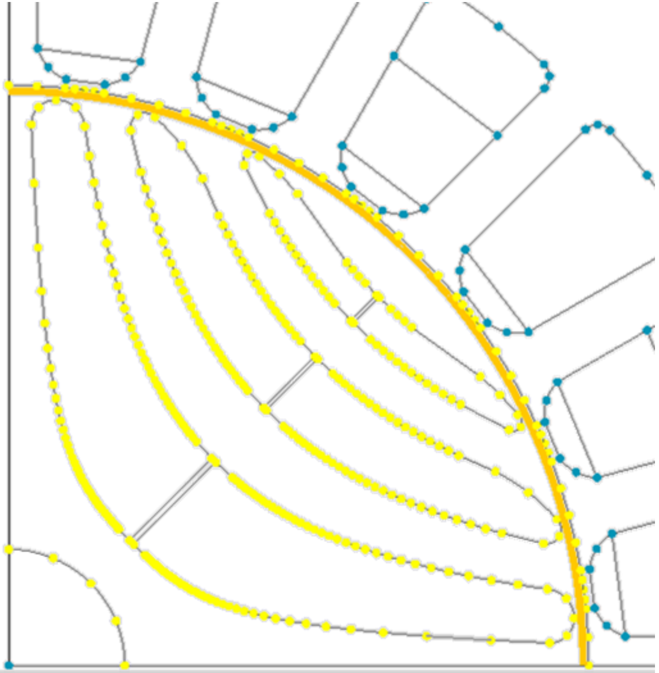


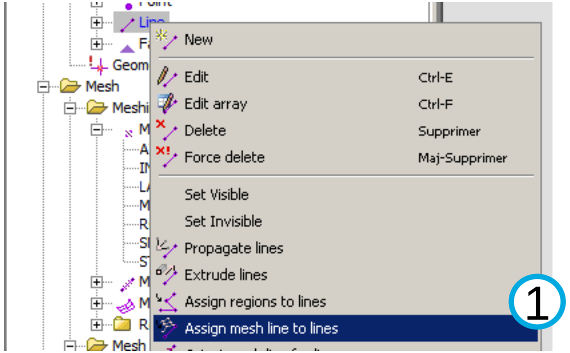
Meshing

- Assign mesh line to lines

Step	Action
1	Go to [Data Tree] -> [Geometric] -> [Geometric entities] -> [Line] ->[Assign mesh line to lines]
2	Assign “AIRGAP_MESH” to central airgap lines and to the limit between rotor and airgap,as shown in the figure







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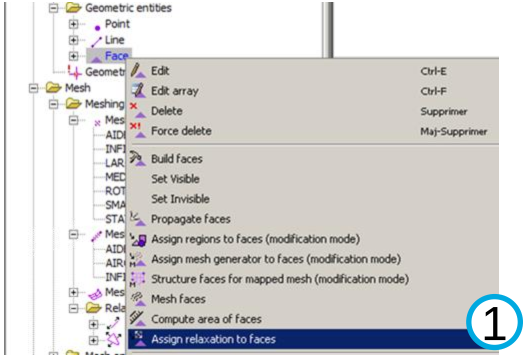
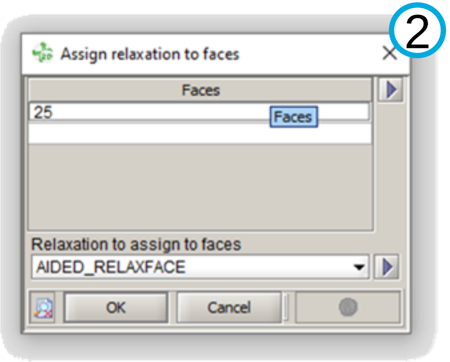
Meshing

- Assign relaxation to faces

Step	Action
1	Go to [Data Tree] -> [Geometric] -> [Geometric entities] -> [Face] ->[Assign relaxation to faces]
2	Assign "AIDED_RELAXFACE" to rotor's face, as shown in the figure





Meshing

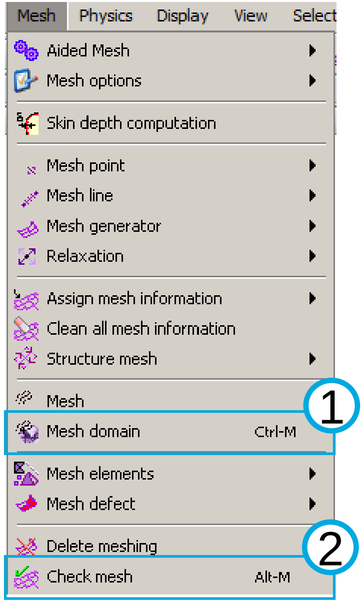
- Mesh and check the resulting mesh
- Shape optimization process is very sensible to the quality of the mesh in the region to be optimized

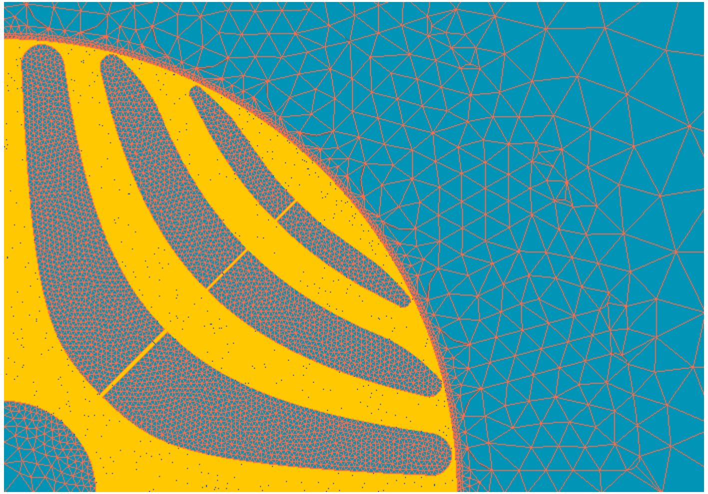
Step	Action
1	Go to menu [Mesh] -> [Mesh domain]
2	Check mesh quality through menu [Mesh] -> [Check mesh]

```
Surface elements :
   Number of elements not evaluated      : 0   %
   Number of excellent quality elements : 98.7  %
   Number of good quality elements       : 0.94  %
   Number of average quality elements    : 0.28  %
   Number of poor quality elements       : 0.08  %

Number of nodes : 34139
Number of line elements : 1750
Number of surface elements : 16938
Mesh order : 2nd order
```

Check mesh results





Results of the meshing process

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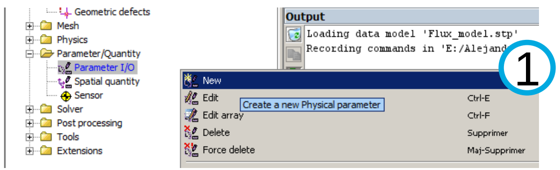
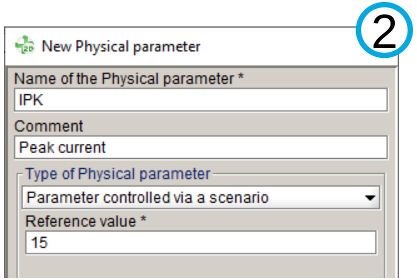
STEP BY STEP TUTORIAL – PHYSICS

Physics

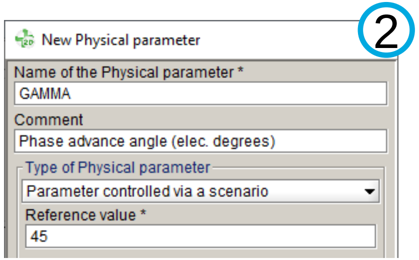
- Define I/O parameters

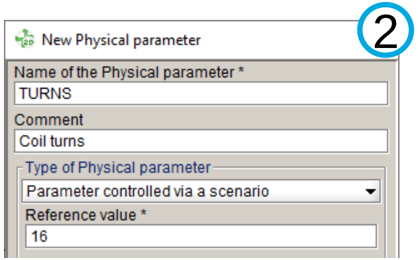
Step	Action
1	Go to [Data Tree] -> [Parameter/Quantity] -> [Parameter I/O] ->[New]
2	Define three I/O parameters as indicated in the table below





Parameter I/O	Value
IPK: Peak current	15
GAMMA: Phase angle (electric degrees)	45
TURNS: Coil's turns	16



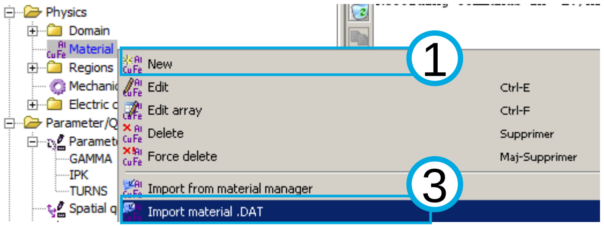


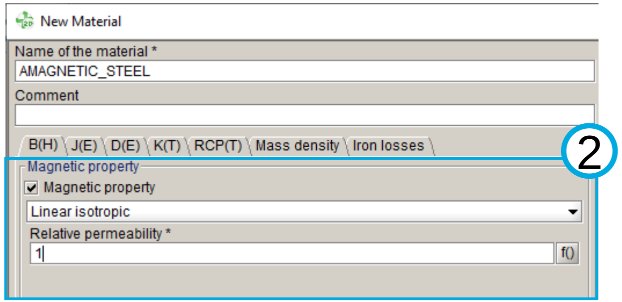
ALTAIR

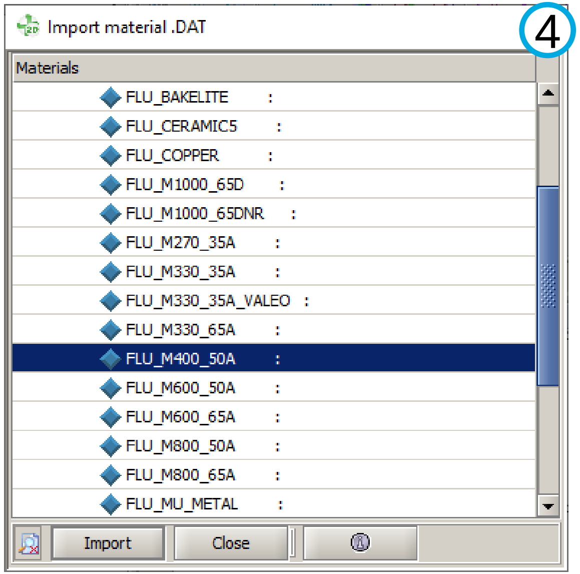
Physics

- Define physics materials

Step	Action
1	Go to [Data Tree] -> [Physic] -> [Material] ->[New]
2	Define a non-magnetic steel AMAGNETIC-STELL as shown in the figure
3	Go to [Data Tree] -> [Physic] -> [Material] ->[Import material .DAT
4	Load predefined material FLU_M400_50A



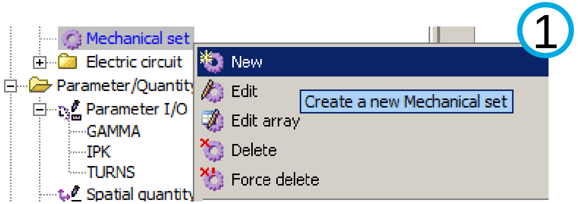


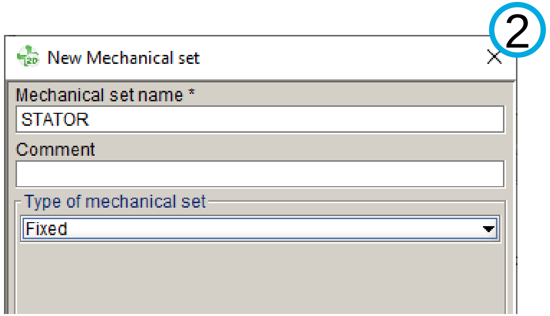


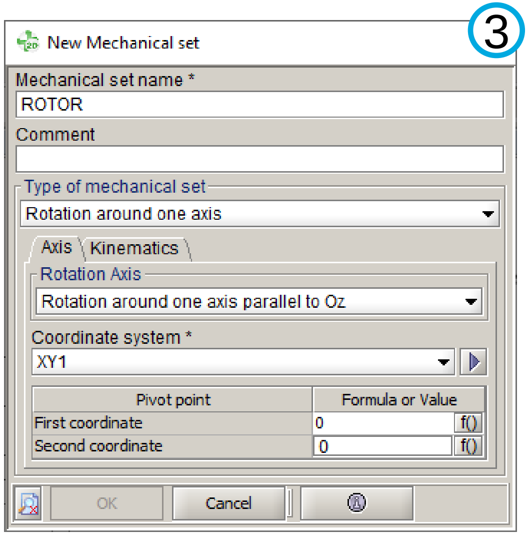
Physics

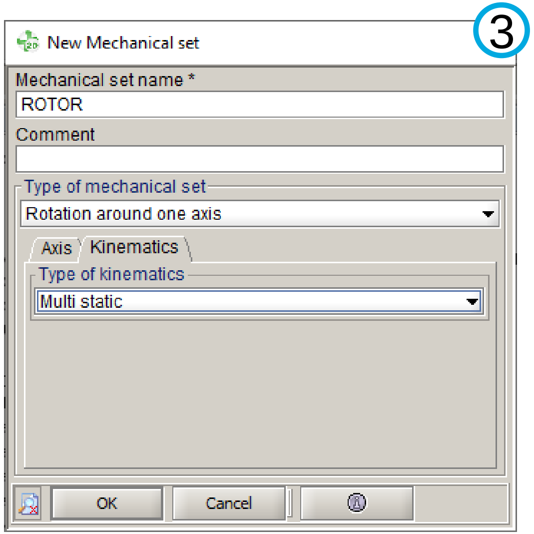
- Define mechanical sets

Step	Action
1	Go to [Data Tree] -> [Physic] -> [Mechanical set] ->[New]
2	Define STATOR as fixed mechanical set
3	Define ROTOR as multi-static mechanical set rotating around (0,0)









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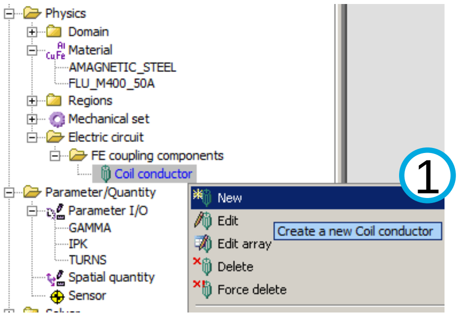
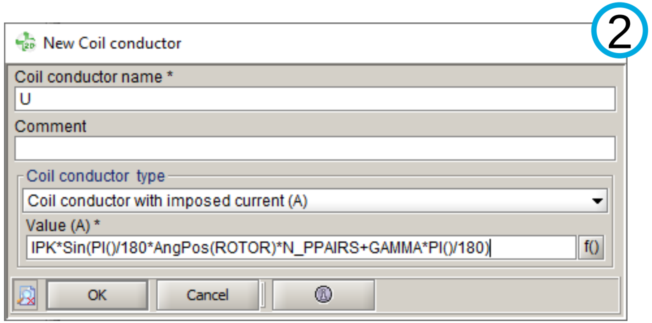
Physics

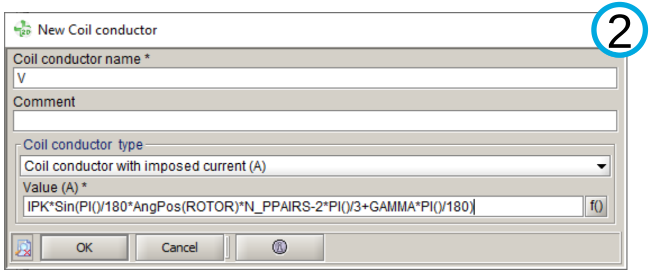
- Define coil conductors as balanced three-phase system

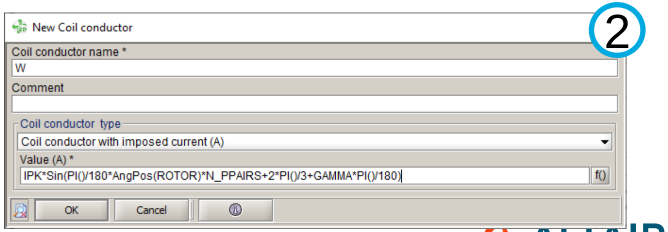
Step	Action
1	Go to [Data Tree] -> [Physic] -> [Electric Circuit] ->[FE coupling components]->[Coil conductor]->[New]
2	Define three coil conductors as indicated in the table below

Coil conductor	Value (A)
U	*IPK*Sin(PI()/180*AngPos(ROTOR)*N_PPAIRS+GAMMA*PI()/180)*
V	*IPK*Sin(PI()/180*AngPos(ROTOR)*N_PPAIRS-2*PI()/3+GAMMA*PI()/180)*
W	*IPK*Sin(PI()/180*AngPos(ROTOR)*N_PPAIRS+2*PI()/3+GAMMA*PI()/180)*





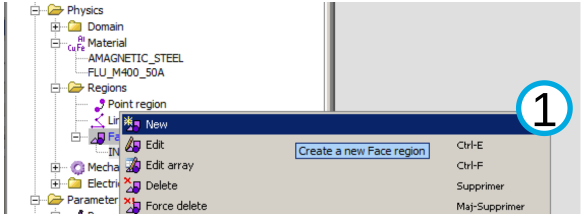


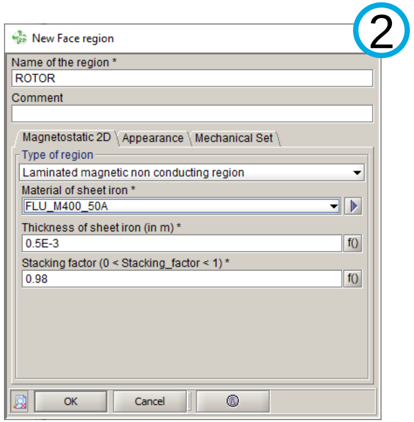


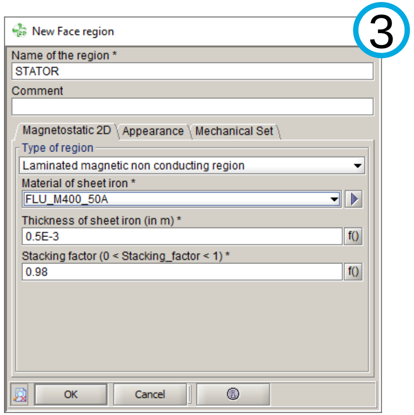
Physics

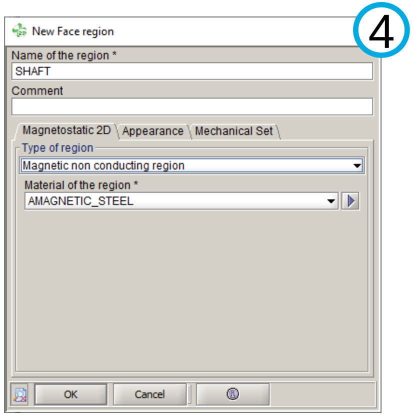
- Create face regions

Step	Action
1	Go to [Data Tree] -> [Physic] -> [Regions] ->[Face regions]->[New]
2	Define ROTOR face region as shown in the image
3	Define STATOR face region as shown in the image
4	Define SHAFT face region as shown in the image





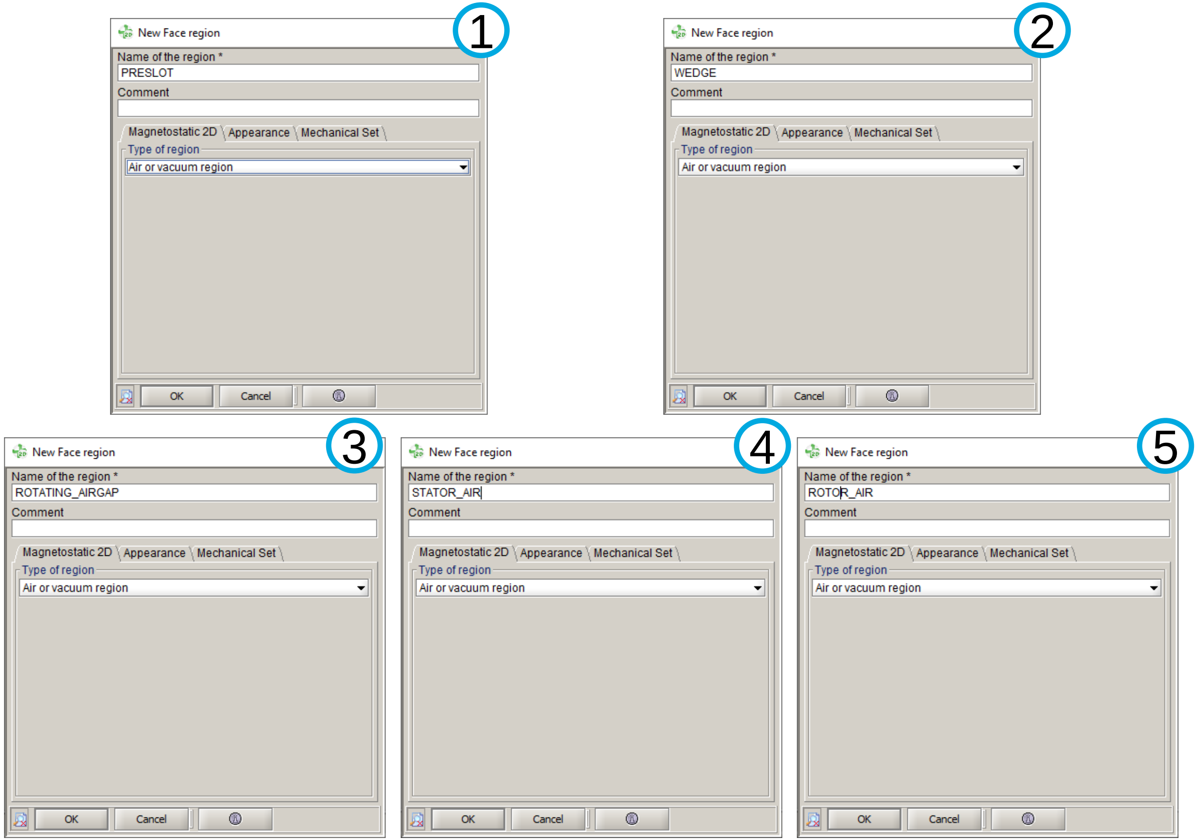




Physics

- Create face regions

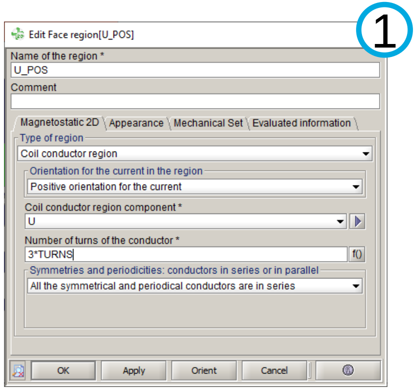
Step	Action
1	Define PRESLOT face region as shown in the image
2	Define WEDGE face region as shown in the image
3	Define ROTATING_AIRGAP face region as shown in the image
4	Define ROTOR_AIR face region as shown in the image
5	Define STATOR_AIR face region as shown in the image

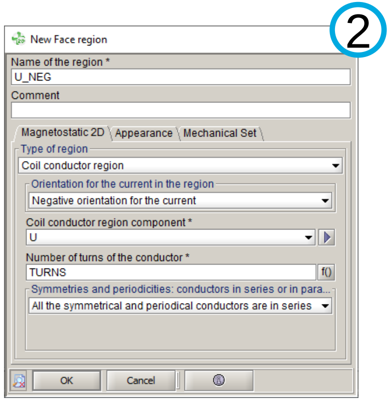


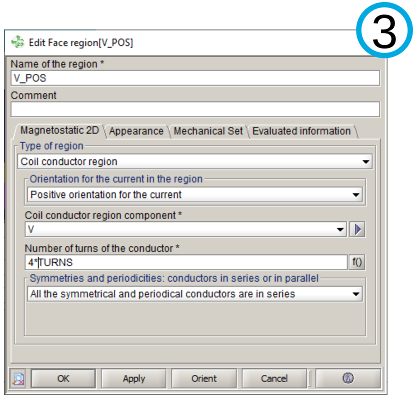
Physics

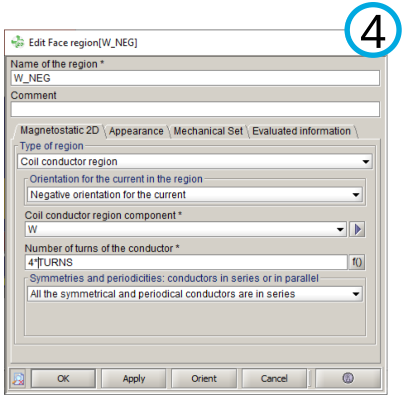
- Create face regions

Step	Action
1	Define U_POS face region as shown in the image
2	Define U_NEG face region as shown in the image
3	Define V_POS face region as shown in the image
4	Define W_NEG face region as shown in the image







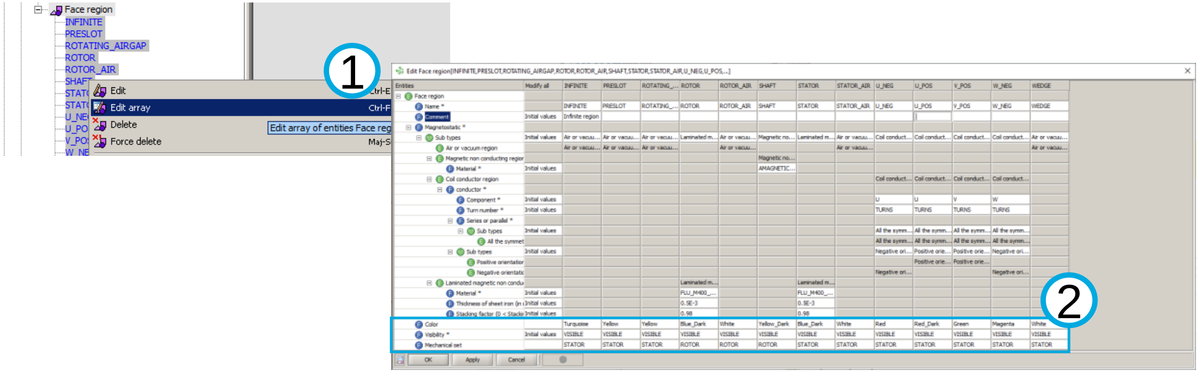


ALTAIR

Physics

- Assign mechanical set and colors to phase regions
- Region’s color are optional but highly recommended

Step	Action
1	Go to [Data Tree] -> [Physic] -> [Regions] ->[Face regions]-> Select all regions ->[Edit array]
2	Update Color and Mechanical set as shown in the figure



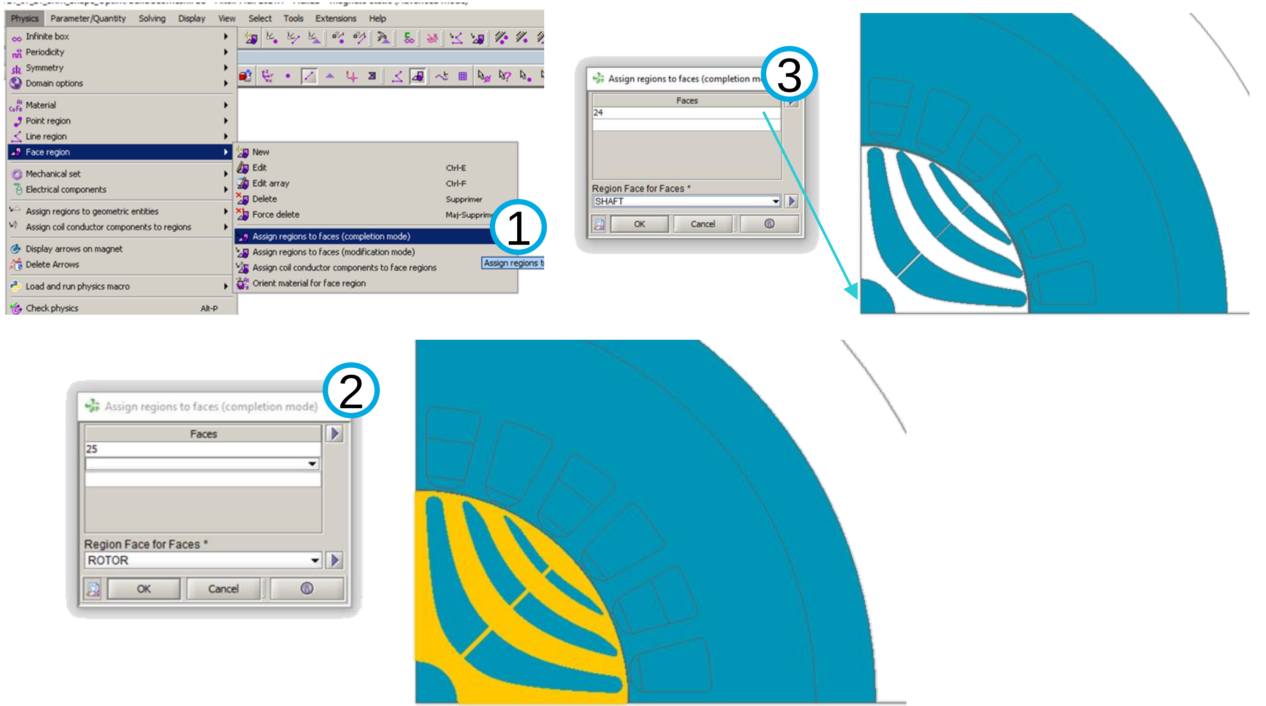
Face region	Infinite	Preslot	Rotating _airgap	Rotor	Rotor_ air	Shaft	Stator	Stator_ air	U_neg	U_pos	V_pos	W_neg	Wedge
Proposed colour	Turquoise	Yellow	Yellow	Blue Dark	White	Yellow Dark	Blue Dark	White	Red	Red Dark	Green	Magenta	While
Mechanical set	Stator	Stator	Stator	Rotor	Rotor	Rotor	Stator	Stator	Stator	Stator	Stator	Stator	Stator

ALTAIR

Physics

- Assign region to faces

Step	Action
1	Go to menu [Physics] -> [Face region]->[Assign regions to faces (competition mode)]
2	Assign face to ROTOR as shown in the image
3	Assign face to SHAFT as shown in the image



ALTAIR

Physics

- Assign region to faces

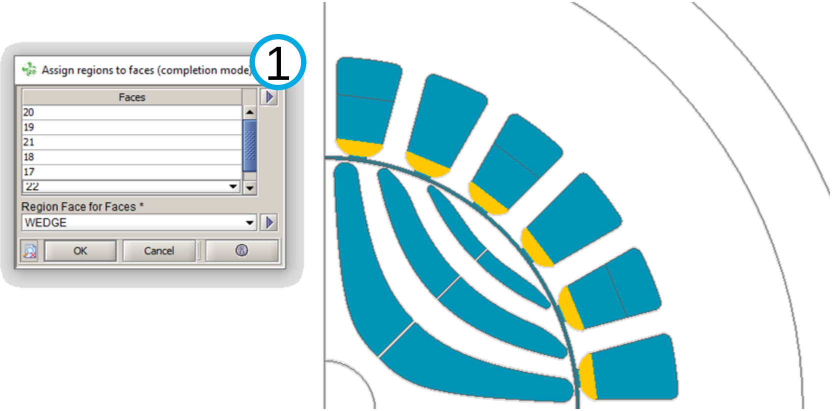
Step	Action
1	Assign face to STATOR as shown in the image
2	Assign face to STATOR_AIR as shown in the image

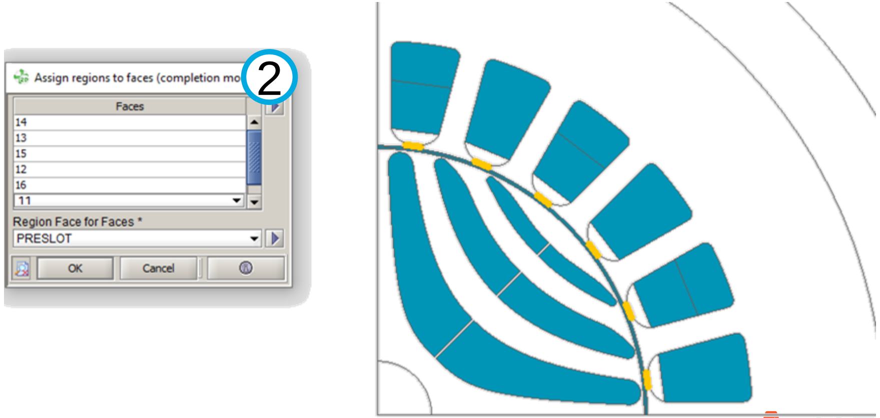
ALTAIR

Physics

- Assign region to faces

Step	Action
1	Assign faces to WEDGE as shown in the image
2	Assign faces to PRESLOT as shown in the image



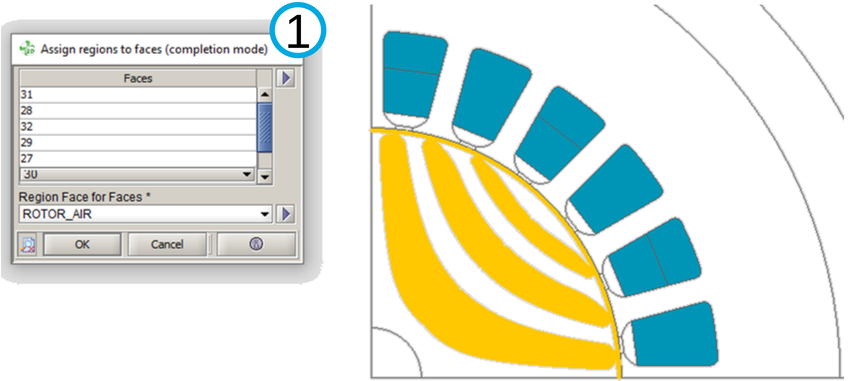


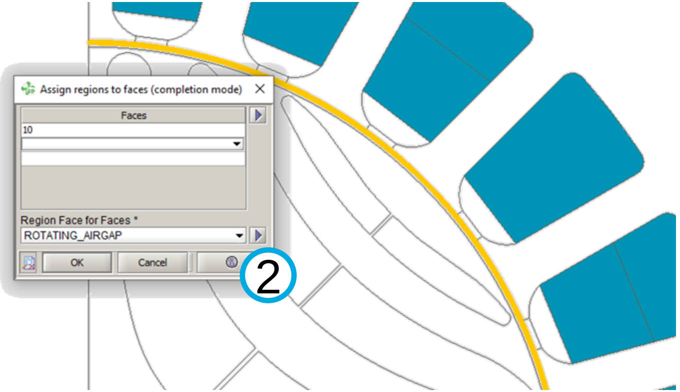
ALTAIR

Physics

- Assign region to faces

Step	Action
1	Assign faces to ROTOR_AIR as shown in the image
2	Assign face to ROTATING_AIRGAP as shown in the image



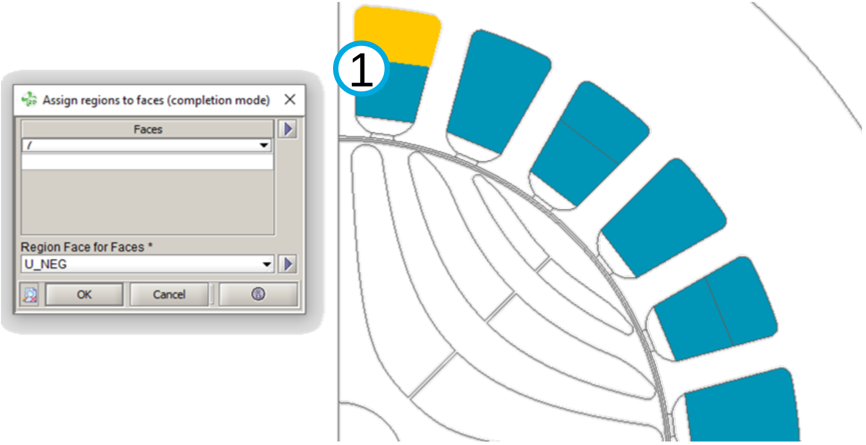


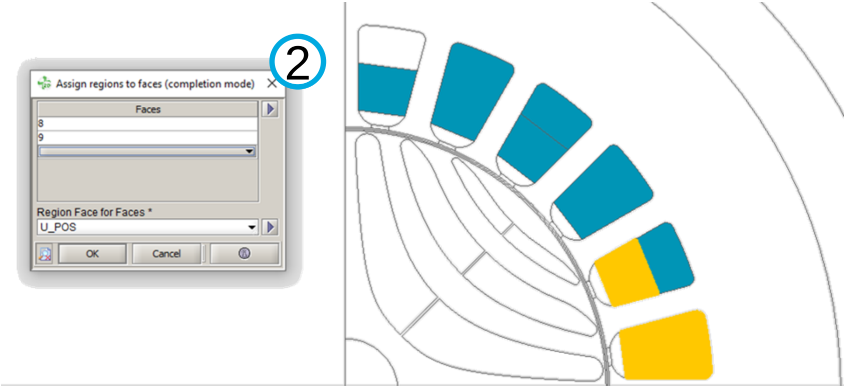
ALTAIR

Physics

- Assign region to faces

Step	Action
1	Assign faces to U_NEG as shown in the image
2	Assign faces to U_POS as shown in the image



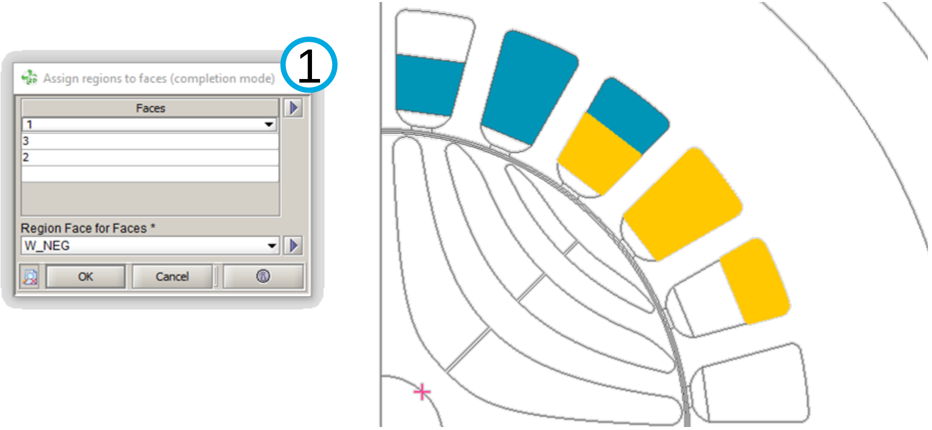


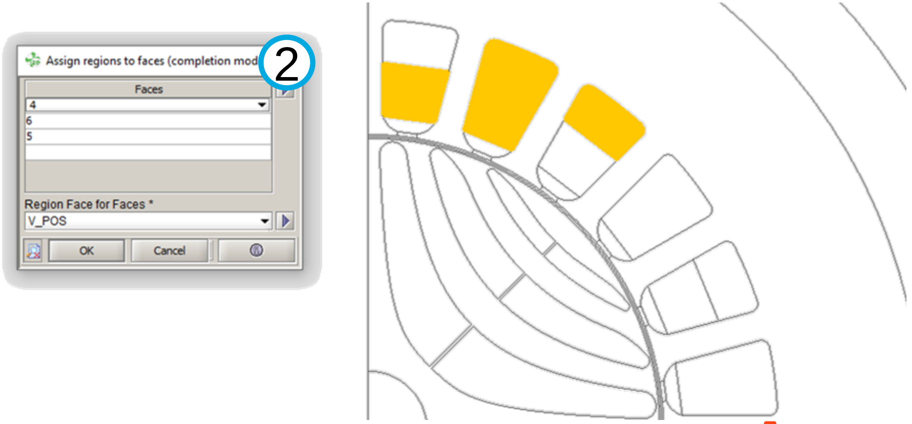
ALTAIR

Physics

- Assign region to faces

Step	Action
1	Assign faces to W_NEG as shown in the image
2	Assign faces to V_POS as shown in the image



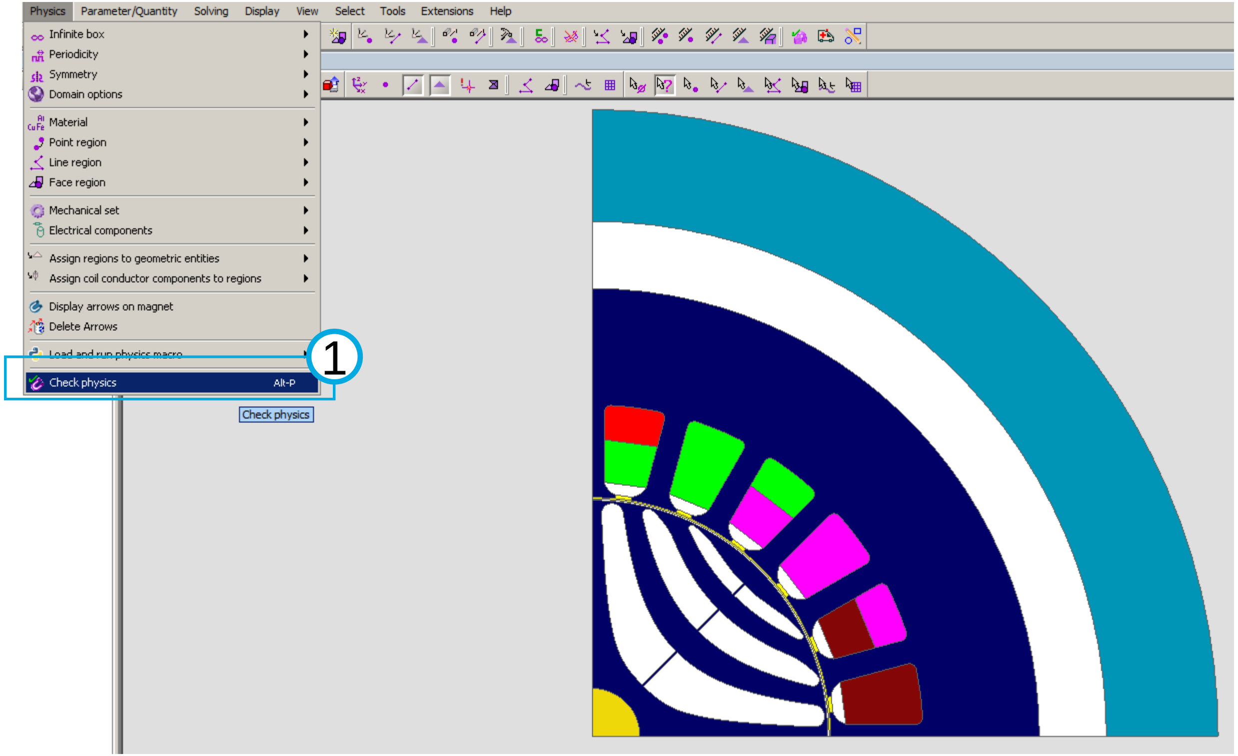


ALTAIR

Physics

- Check the resulting physics
- Final aspect of the SRM model is shown below

Step	Action
1	Check physics through menu [Physics] -> [Check physics]



ALTAIR

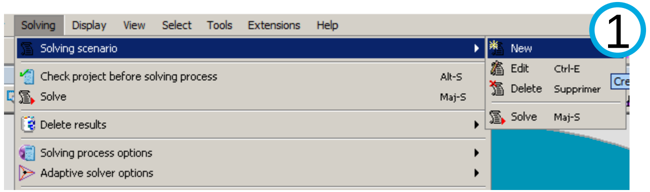
STEP BY STEP TUTORIAL – OPTIMIZATION

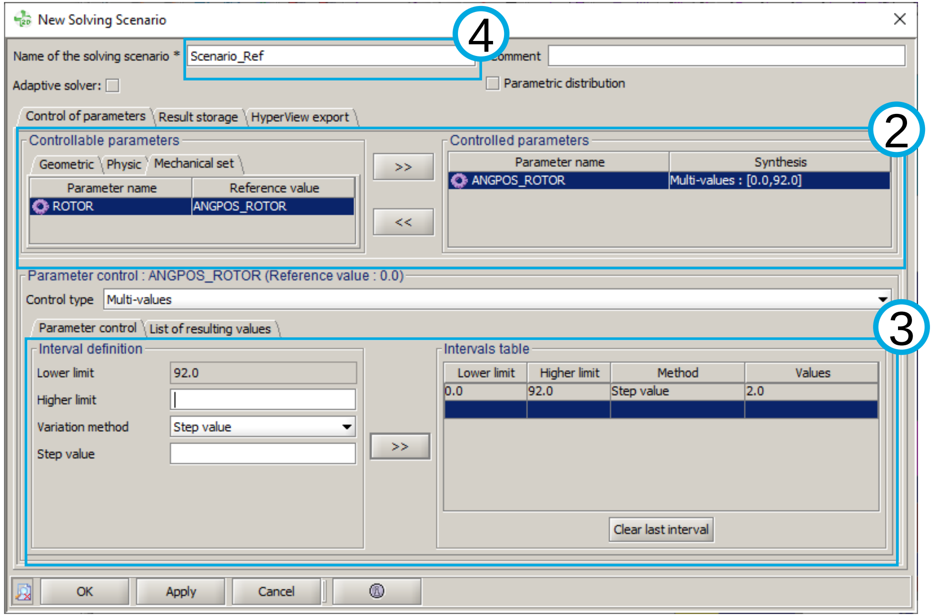
ALTAIR

Solving

- Define solving scenario

Step	Action
1	Go to menu [Solving] -> [Solving Scenario] ->[New]
2	In controllable parameters select the tab [Mechanical_set] and select the parameter ANGPOS_ROTOR
3	The parameter will vary from 0º to 92º with a step of 2º
4	Name the scenario as Scenario_Ref



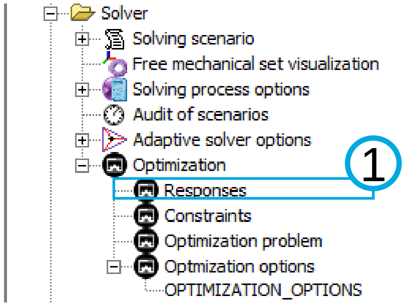


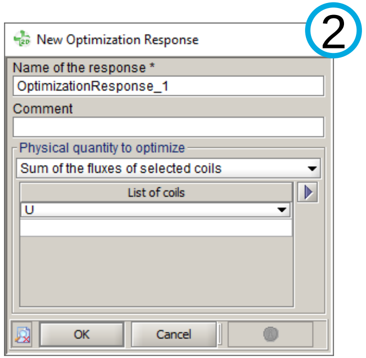
ALTAIR

Solving

- Define shape optimization responses

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Responses] ->[New]
2	Define the flux through the coil U as the response



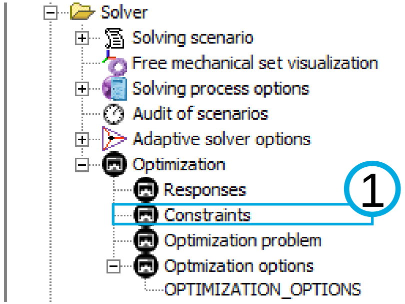


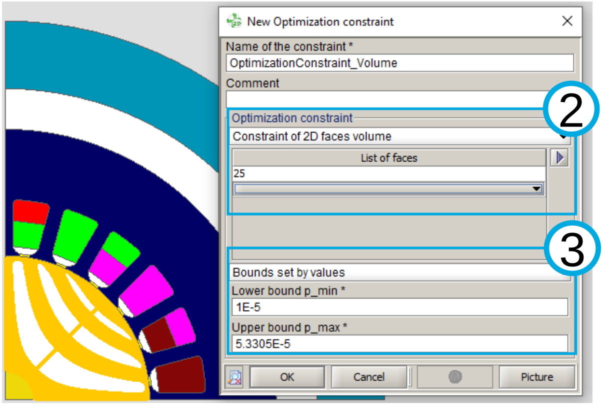
ALTAIR

Solving

- Define shape optimization constraints used in cases 2 and 3

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Constraints] ->[New]
2	Select “Constraint of 2D faces volumes” and select the rotor’s face
3	Select the “bounds set by values” and establish upper bound at 5.33E-5 m^2 (80% of the current rotor volume)

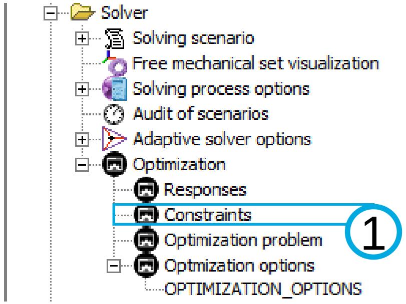


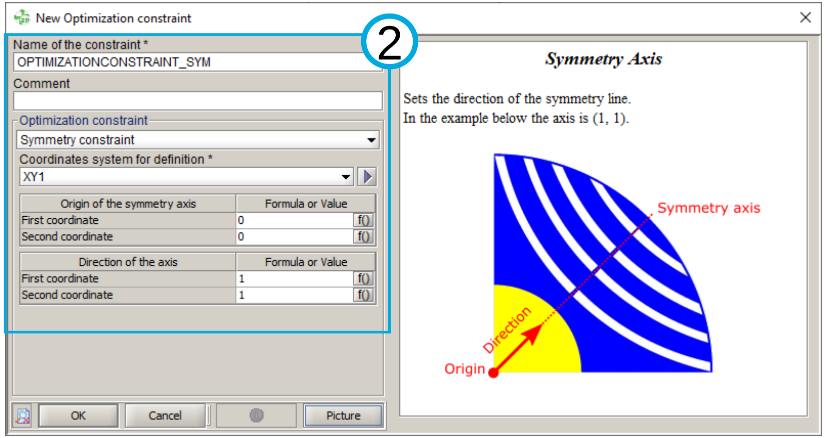


Solving

- Define shape optimization constraints used in cases 3

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Constraints] ->[New]
2	Impose the rotor’s symmetry as constrains and shown in the figure





Solving

- Creation of the compose file

The name of the function must be "Obj_Func"

- rparam is the input values coming from the "Responses" defined in the previous slides. In our case it is the flux through the coil U
- rresp will be the response used by Optistruct to perform the optimization (in this case the torque)

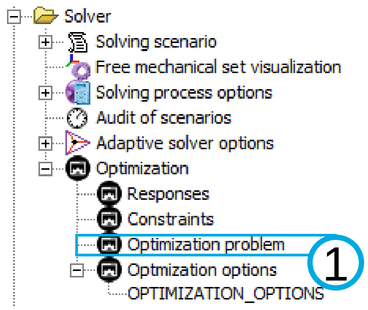
```
function [rresp, dresp, udata] = Obj_Func (iparam, rparam, nparam, iresp, rresp, dresp, nresp, isens, udata)
%   iparam - vector of ints
%   rparam - vector of doubles
%   nparam - size of input vector
%   iresp - vector of ints
%   rresp - output parameter (vector of ints)
%   dresp - output parameter (matrix of MxN dimension)
%   nresp - size of output vector
%   isens - sensitivity flag
%   udata - userdata

    %Scenario/project values
    Angpos=[2:2:180]; %Rotor angular position (for currents)
    n=[0:44,-45:-1]; %fft index for 90 samples in one period
    P=2; %Number of pole pairs
    c_angle=45; %Control angle (°)
    Ipk=15; %Peak current (Apk)
    %Read flux in phase 1 from flux project and build flux in phase 2 and 3 from it
    flux = rparam;
    ph1=[flux(2:end),-flux(3:end-1)];
    PH1=fft(ph1);
    PH2=PH1.*exp(-j*2*pi/3*n);
    PH3=PH1.*exp(j*2*pi/3*n);
    ph2=ifft(PH2);
    ph3=ifft(PH3);

    %Rebuild currents that are fed in Flux project
    I1= Ipk*sin(pi/180*(Angpos*P+c_angle));          %Current in phase 1
    I2= Ipk*sin(pi/180*(Angpos*P+c_angle)-2*pi/3);    %Current in phase 2
    I3= Ipk*sin(pi/180*(Angpos*P+c_angle)+2*pi/3);    %Current in phase 3
    save('auxiliar.mat','flux')
    %Output (torque's mean value over one period)
    T = P/sqrt(3)*(I1.*(ph3-ph2)+I2.*(ph1-ph3)+I3.*(ph2-ph1));
    rresp(1) = mean(T);
end
```

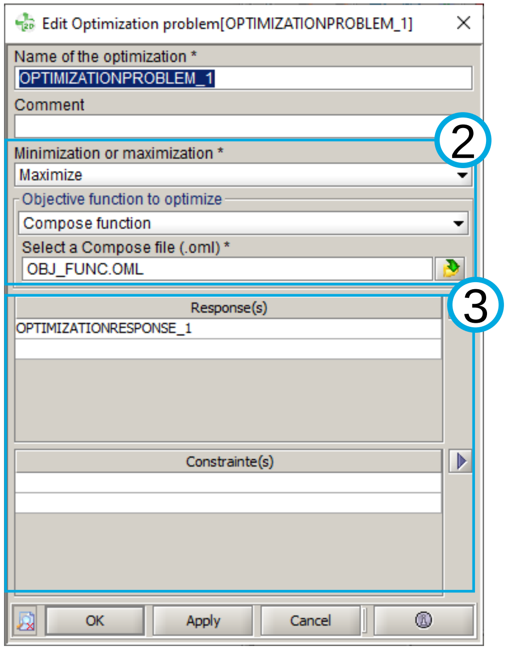

ALTAIR

Solving

- Case 1 : optimization problem
- Shape optimization of the mean torque using optimization function programmed in Altair Compose file. No optimization constrains are applied.

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Optimization problem] ->[New]
2	Select maximize the objective function, defined through a Compose file (see slide 13)
3	Select the responses previously defined





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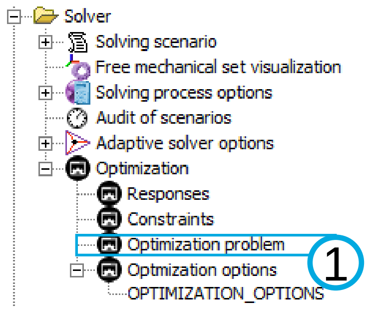
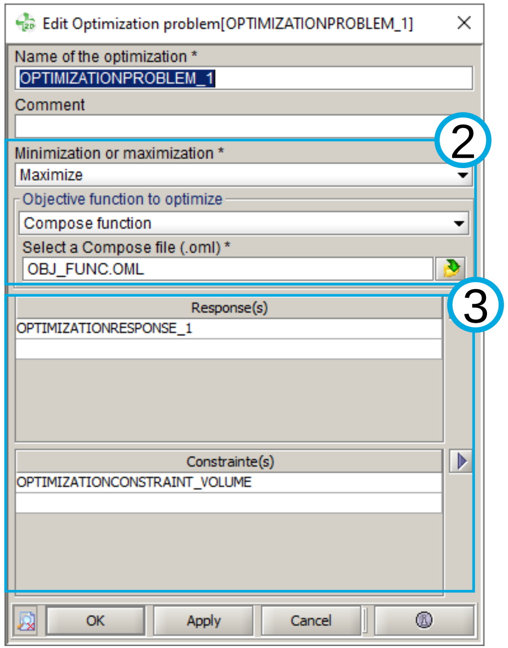
Solving

- Case 2 : optimization problem
- Shape optimization of the mean torque using optimization function programmed in Altair Compose file. In this case a rotor mass reduction > 20% will be imposed.

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Optimization problem] ->[New]
2	Select maximize the objective function, defined through a Compose file (see slide 13)
3	Select the responses and the volume constraint previously defined

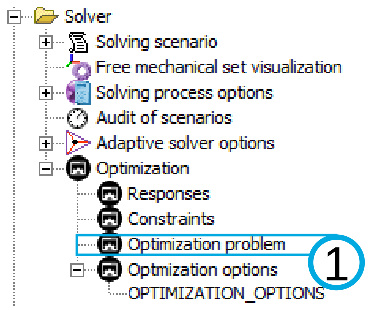


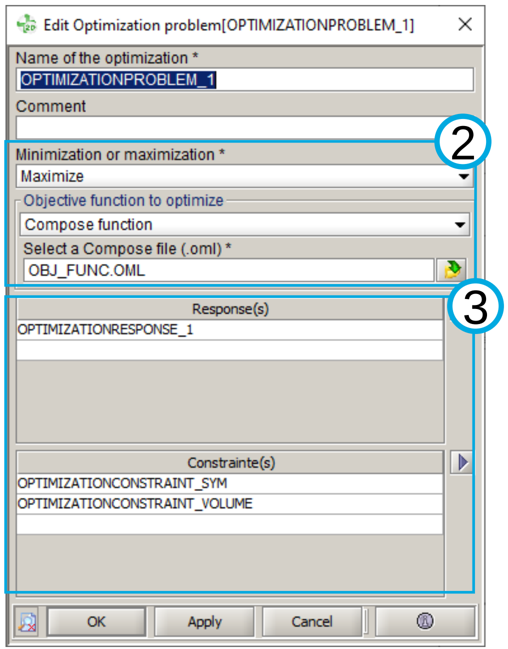


Solving

- Case 3 : optimization problem
- Shape optimization of the mean torque using optimization function programmed in Altair Compose file fulfilling two constrains: Rotor symmetry and a reduction mass of the rotor > 20%.

Step	Action
1	Go to [Data Tree] -> [Solver] -> [Optimization] -> [Optimization problem] ->[New]
2	Select maximize the objective function, defined through a Compose file (see slide 13)
3	Select the responses and the symmetry and volume constraint previously defined





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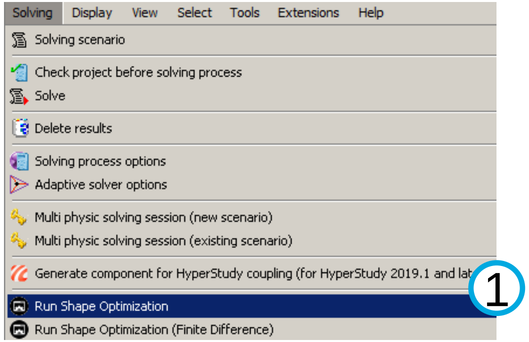
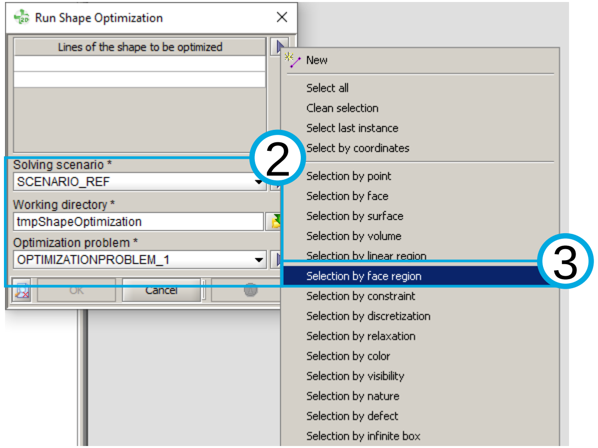
Solving

- Launch shape optimization

Step	Action
1	Go to menu [Solving]->[Run Shape Optimization]
2	Select solving scenario, optimization problem and shape optimization working directory
3	To select the lines of the shape to be optimized click on [Selection by face region]

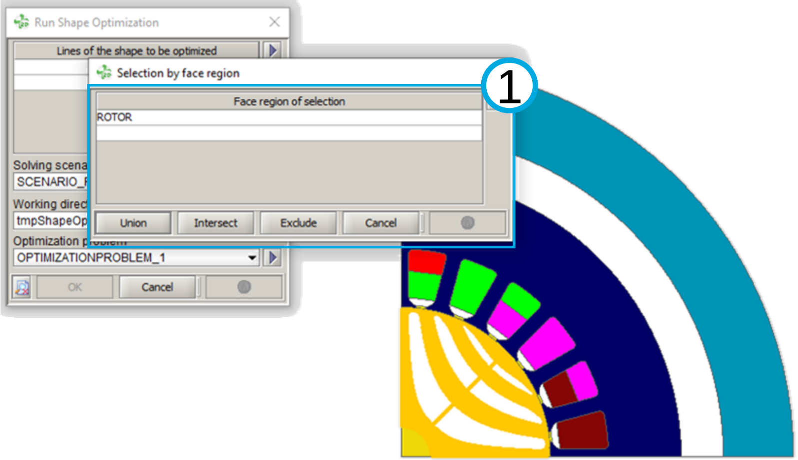


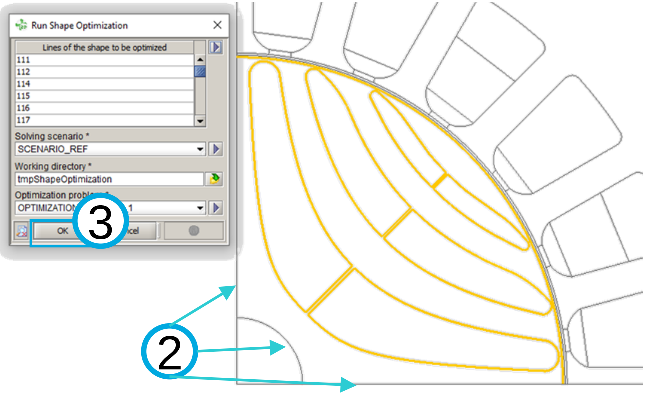


Solving

- Launch shape optimization

Step	Action
1	Select ROTOR as face region and click on [Union]
2	Pushing the case "shift" unselected rotor-shaft limit and right and left rotor's borders
3	Launch optimization process clicking on [OK]. It can take about 90 minutes to be computed



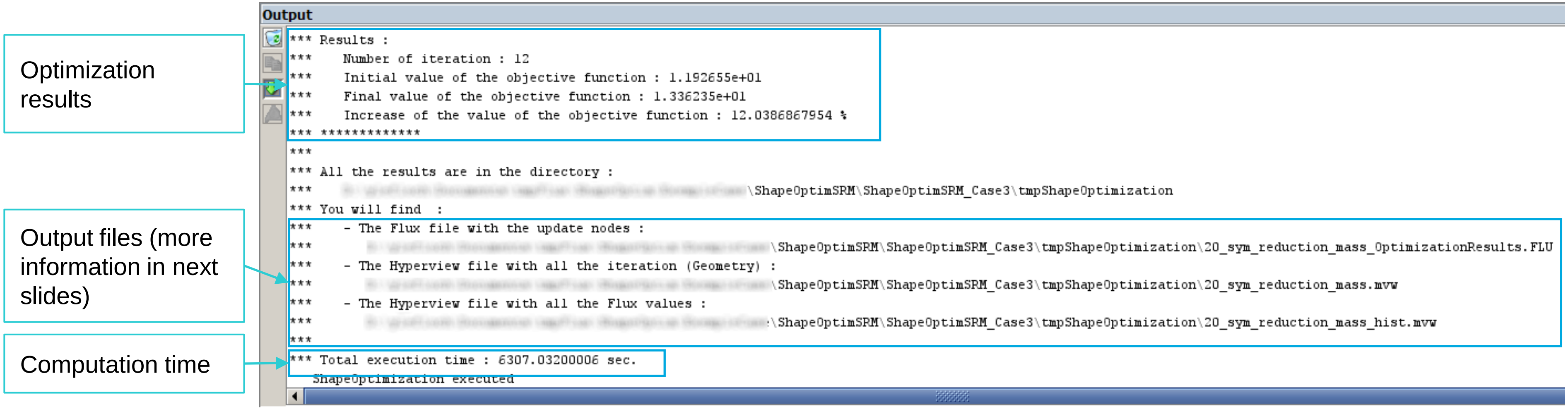


POSTPROCESSING

Postprocessing

Optimization process outputs

- Outputs of the optimization process are shown in Flux, including computation time and % of improvement of the objective function
- The path for three files containing all the optimization process are also provided

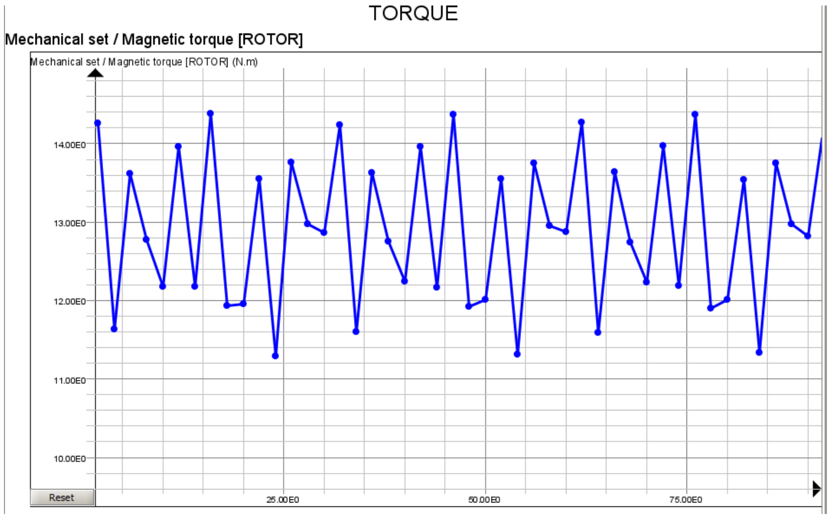


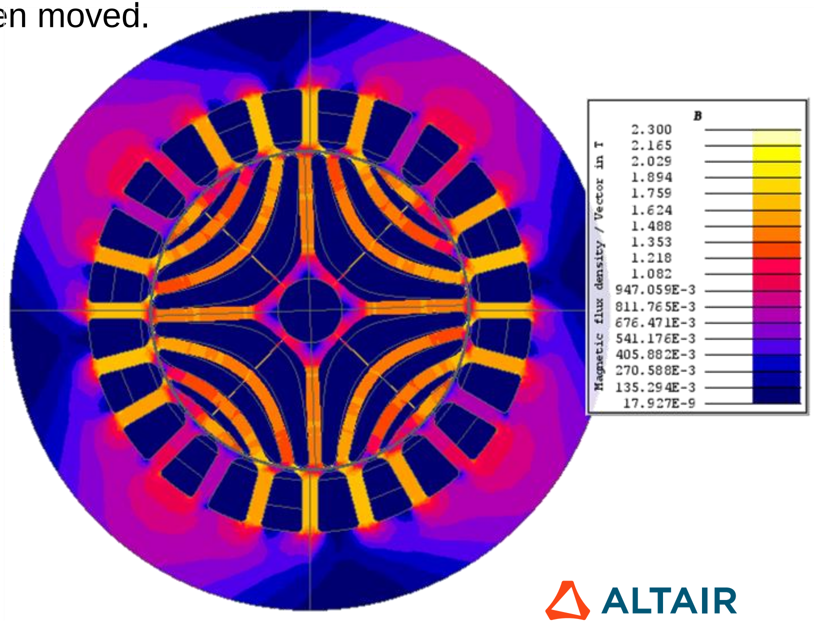
Postprocessing

Flux file with update nodes

- The output project _OptimizationResults.FLU shows the solved Scenario_Ref for the optimized design
- A complete postprocessing can be carried out

The geometry is not updated, only the mesh node have been moved.





Postprocessing

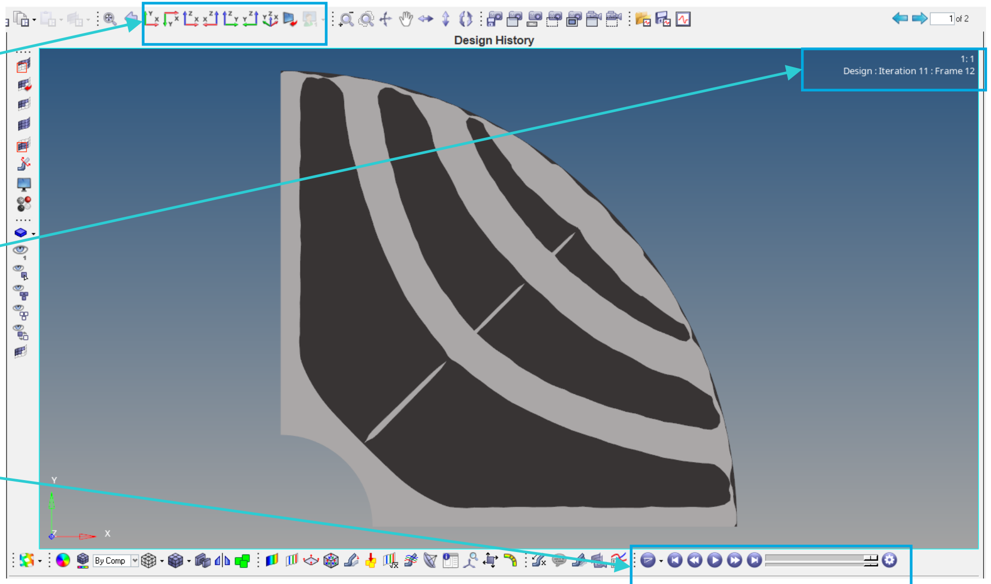
Hyperview file with all the iterations (geometry)

- Contained in optimization working directory *tmpShapeOptimization*
- Hyperview file shows the geometry evolution for each iteration of the optimization process

Select geometry orientation

Iteration of the represented geometry

Animation controls and iterator selector



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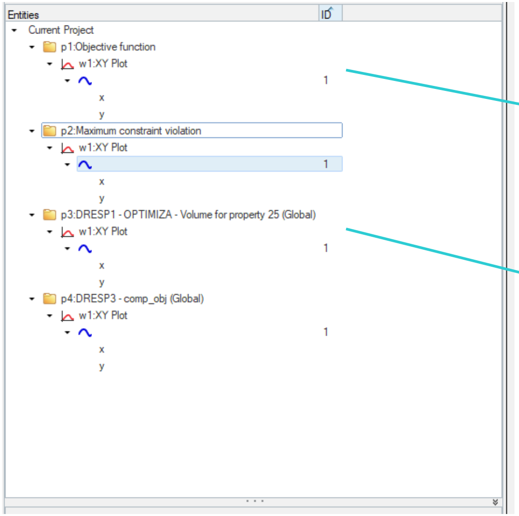
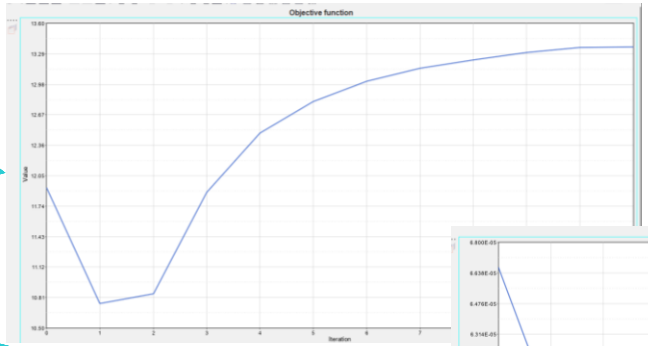
Postprocessing

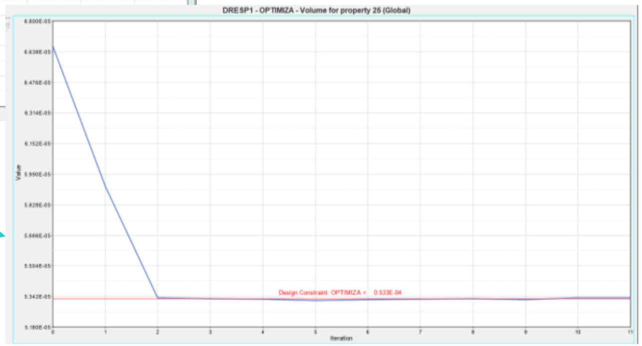
Hyperview file with all the Flux values

- Contained in optimization working directory *tmpShapeOptimization*
- Hyperview file which shows the objective function and the constraints evolution





Objective function evolution



Rotor's volume evolution (constraint in red)

RESULTS

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Results

- As introduced in slide 16, **three optimization process with the same objective function but with different constraints** have been included in this example. The presented tutorial presents the results of the design 3.
- Very good results have been obtained, as it is shown in table below

Design	Mass improv. (%)	Mean torque (Nm)	Torque improv. (%)	Computation time
Initial design	-	11.93	-	-
Design 1 (no restriction)	2.2 %	13.78	15.51 %	62 min
Design 2 (mass reduction ≥ 20%)	20.0 %	13.52	13.40 %	82 min
Design 3 (symmetry imposed and mass reduction imposed)	20.0%	13.36	12.03%	90 min

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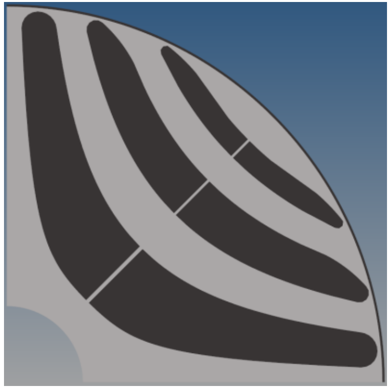
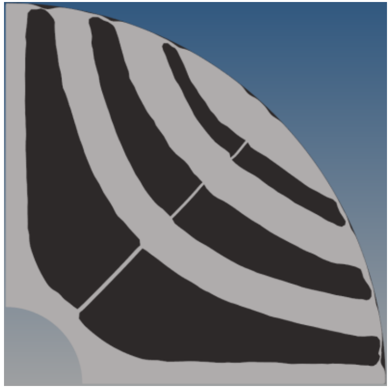
Results

- Rotor shapes obtained by the three optimization processes

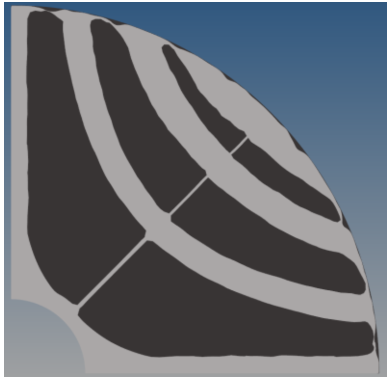
Initial design

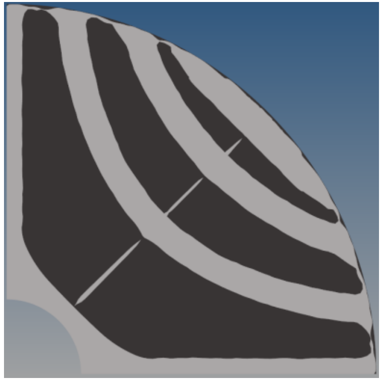




Design 1: No constraints

Design 2: Rotor mass constraint





Design 3: Rotor mass constraint and symmetry imposed

CONCLUSIONS

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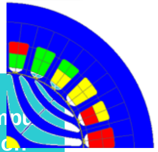
Conclusions

- Shape optimization supposes significant improvement even for initial design with high performances
- High flexibility using Compose to define goal functions
- Fast, robust and efficient
- Let results speak by themselves…



Design	Mass improv. (%)	Torque improv (%)	Computation time
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Design 2 (mass reduction ≥ 20%)	20.0%	13.40%	82 min
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#ONLYFORWARD