smartFEM

Analysis and Design of Electrical Drives

Rotor and Stator Topologies

smartFEM 2.013.00 – 01.03.2022

Content

1 Introduction

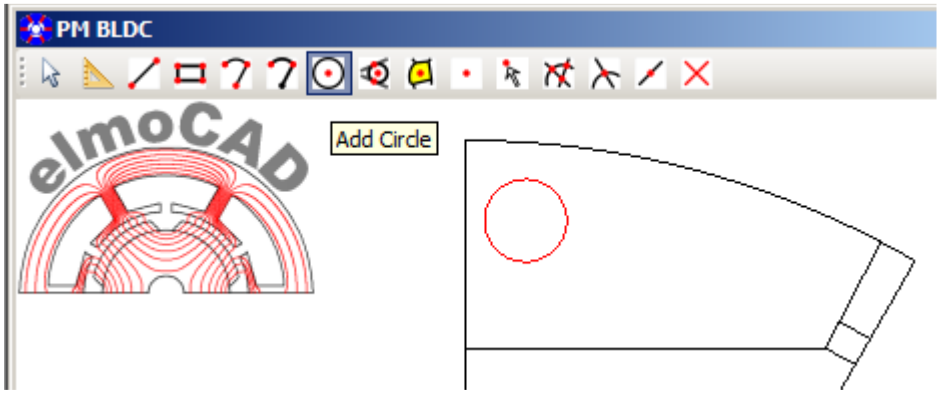
The modeling in smarTFEM is based on pre-programmed rotor and stator topologies with keyboard input of different alphanumeric parameter.

As of release 2.1 offers smartFEM additionally the option for import of dxf-formatted roto and stator geometries. With this all rotor and stator geometries of the same machine type can be combined in any order.

As of release 2.11 all geometries designed with pre-programmed rotor and stator topologies can be enhanced by user defined geometry elements.

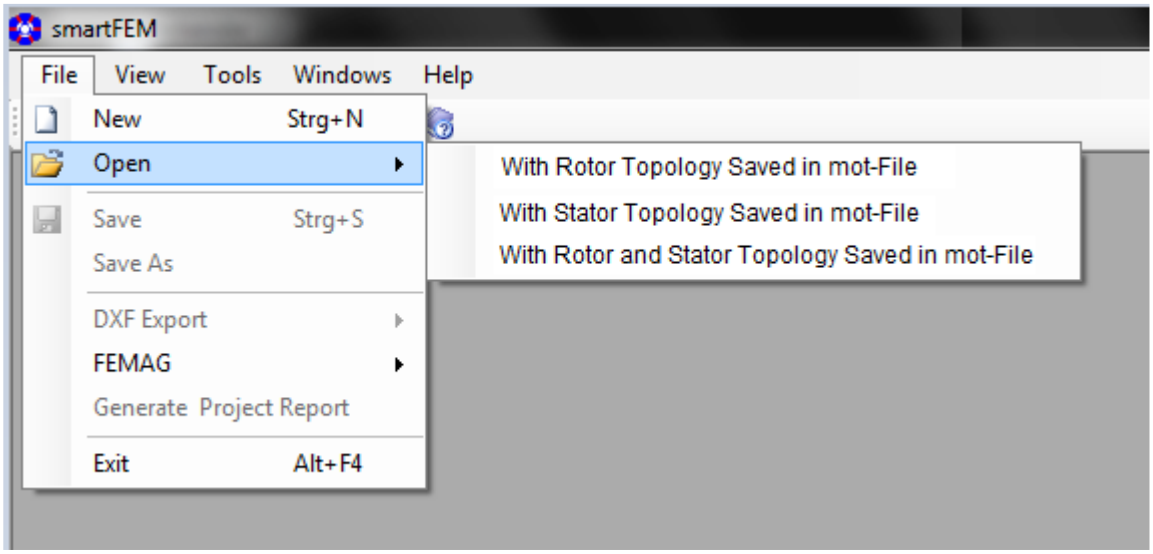
1.1 Changes compared to previous smartFEM releases

User defined geometry elements can be added to geometries which were designed with the pre-programmed rotor and stator topologies. For this is a toolbox with different tool tip buttons available. Details are described in chapter 1.8 of this document.



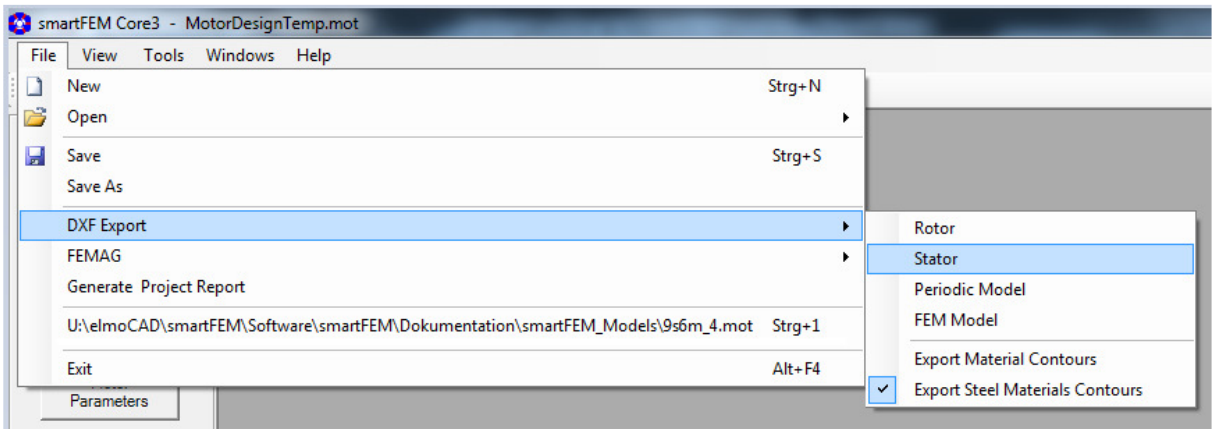
1.2 Opening of simulation models

When openingh simulation models (*.mot files) then the actual releases of the latest release of rotor and stator topologies are loaded. It can happen that after older simulation model are opened not all parameter are correctly displayed because the latest topology release is not upwards compatible If this happens (what should not be) then the simulation model can be opened with those topologies releases with which the simulation model was designed.



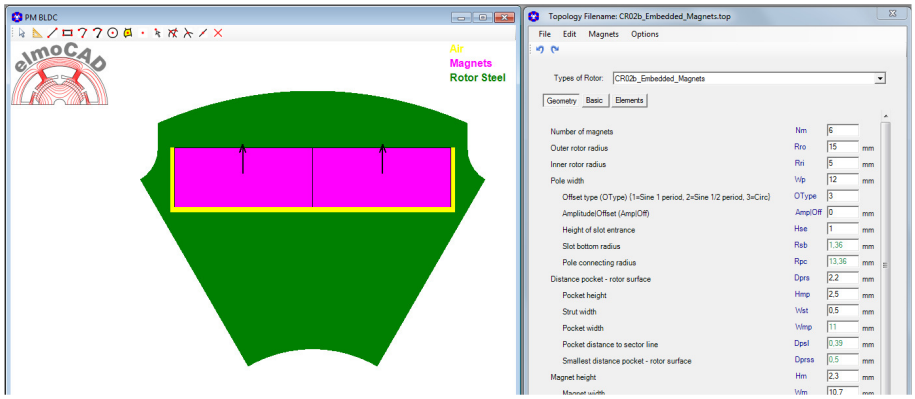
1.3 DFX Export

There are different possibilties exporting geometries into a DXF-formatted file. Example below: export of the stator geometry only with electric steel material contour.

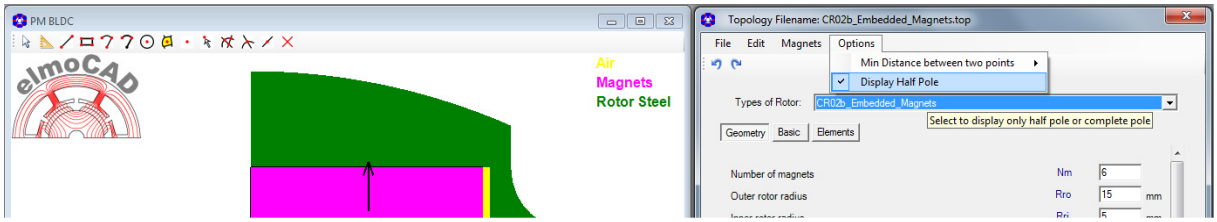


1.4 Minimum Symmetry

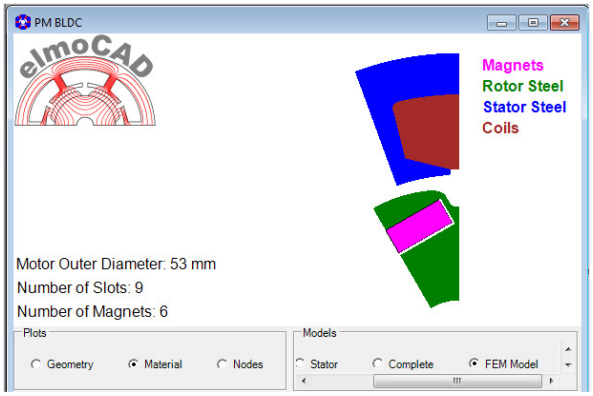
In all topologies the geometry of complete pole is displayed as default.



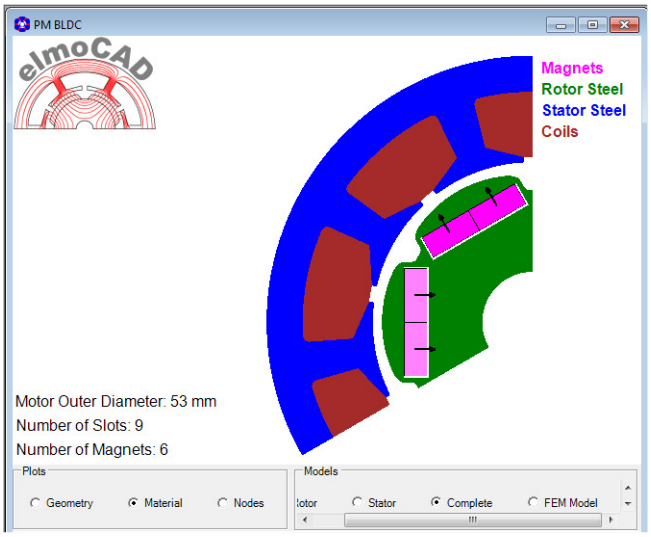
User can select in menu *"Options"* whether the complete or the half geometry of the pole should be displayed (only if the half pole is designed by the topology).



However only the minimal symmetry of the machine geometry is transferred to the FEM solver. With this is avoided that an unbalanced mesh of the complete pole is generated.



The complete geometry (related to the complete BEMAF period) which is neccessary for the FEM simulation is create by mirroring and copying of the minimal symmetries.

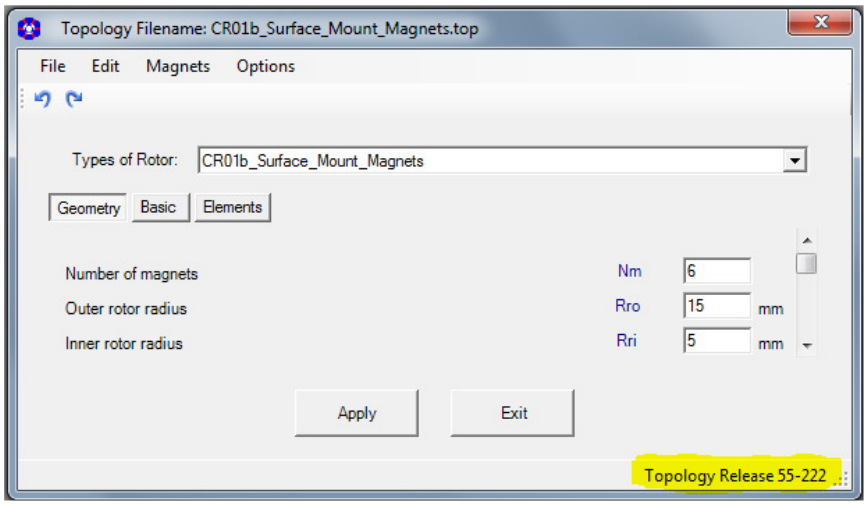


1.5 Parameter

Geometry parameter which are not used in a topology are hidden and only displayed when they are used.

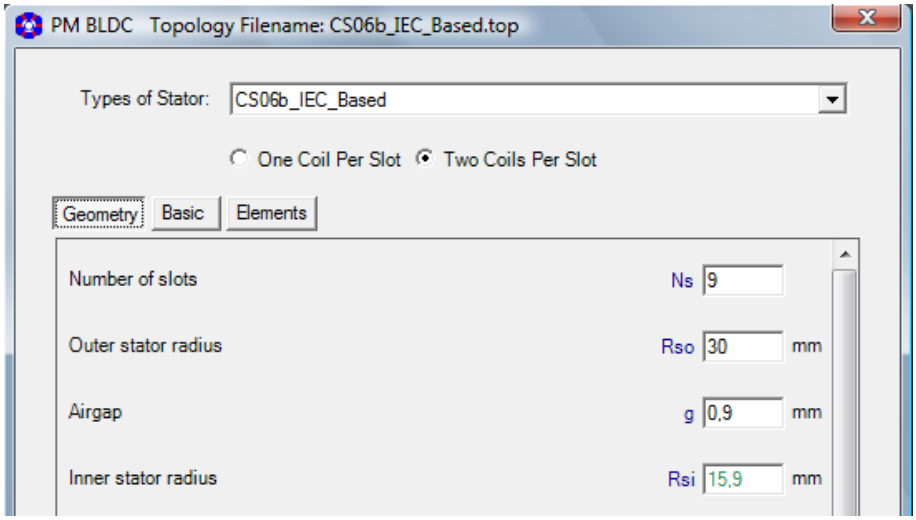
1.6 Release number

The release number of every topology is displayed on the right side of the bottom line.



1.7 Pre-defined parameter of all topologies

1.7.1 Geometry parameter



Machines with inner rotor

Rotor

- Number of magnets Nm = 6
- Outer radius Rro = 15 mm
- Inner radius Rri = 5 mm

Stator

- Number of slots Ns = 9
- Outer radius Rso = 26,5 mm
- Width of airgap (on one side) g = 0,9 mm
- Inner radius (calculated) Rsi = Rro + g mm

Machines with outer rotor

Rotor

- Number of magnets Nm = 12
- Outer radiu Rro = 25 mm
- Inner radius Rri = 20 mm

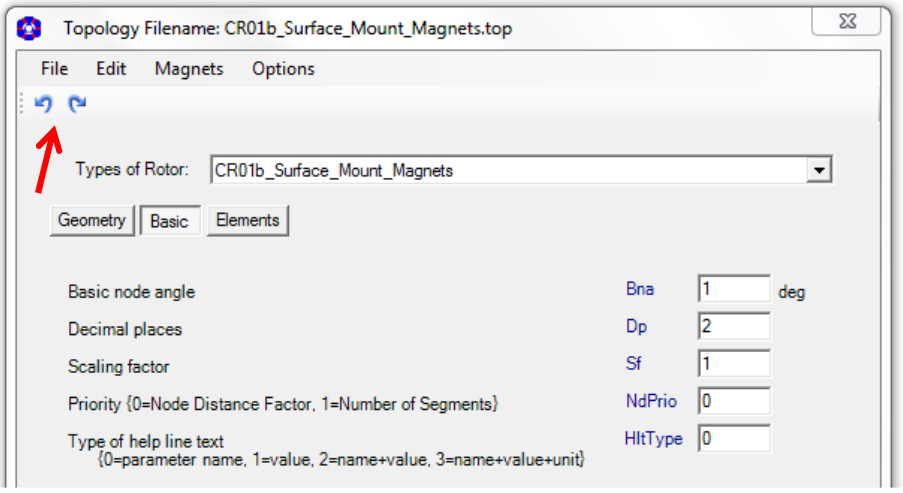
Stator

- Number of slots Ns = 9
- Width of airgap (on one side) g = 0,5 mm
- Outer radius (calculated) Rso = Rri - g mm
- Inner radius Rsi = 5 mm

1.7.2 Basic parameter

All Topologies

UnDo and ReDo button



Bna = Minimal angle between two nodes of inner and outer radius for the geometry at the airgap.

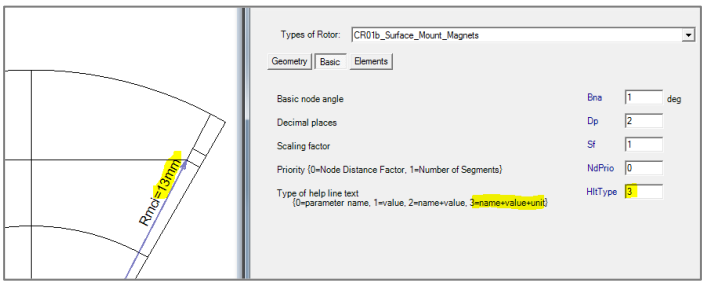
Dp = Number of decimal places of all parameter.

For parameter which are calculated and cannot be changed by user are the calculations performed with the maximum total number of decimal places and rounded for display.

Sf = Scaling factor for all editable parameter values of the geometries.

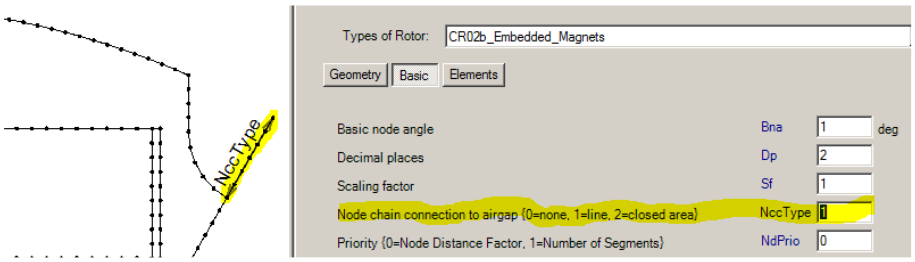
NdPrio = Flag whether in parameter group *"Elements"* the *"Node distance factor"* or *"Number of segmenets"* of an arc or line should be constant if the length of an arc or line has changed.

Type of help line text = the displayed help information of arcs, line, etc. are amended by additional information.



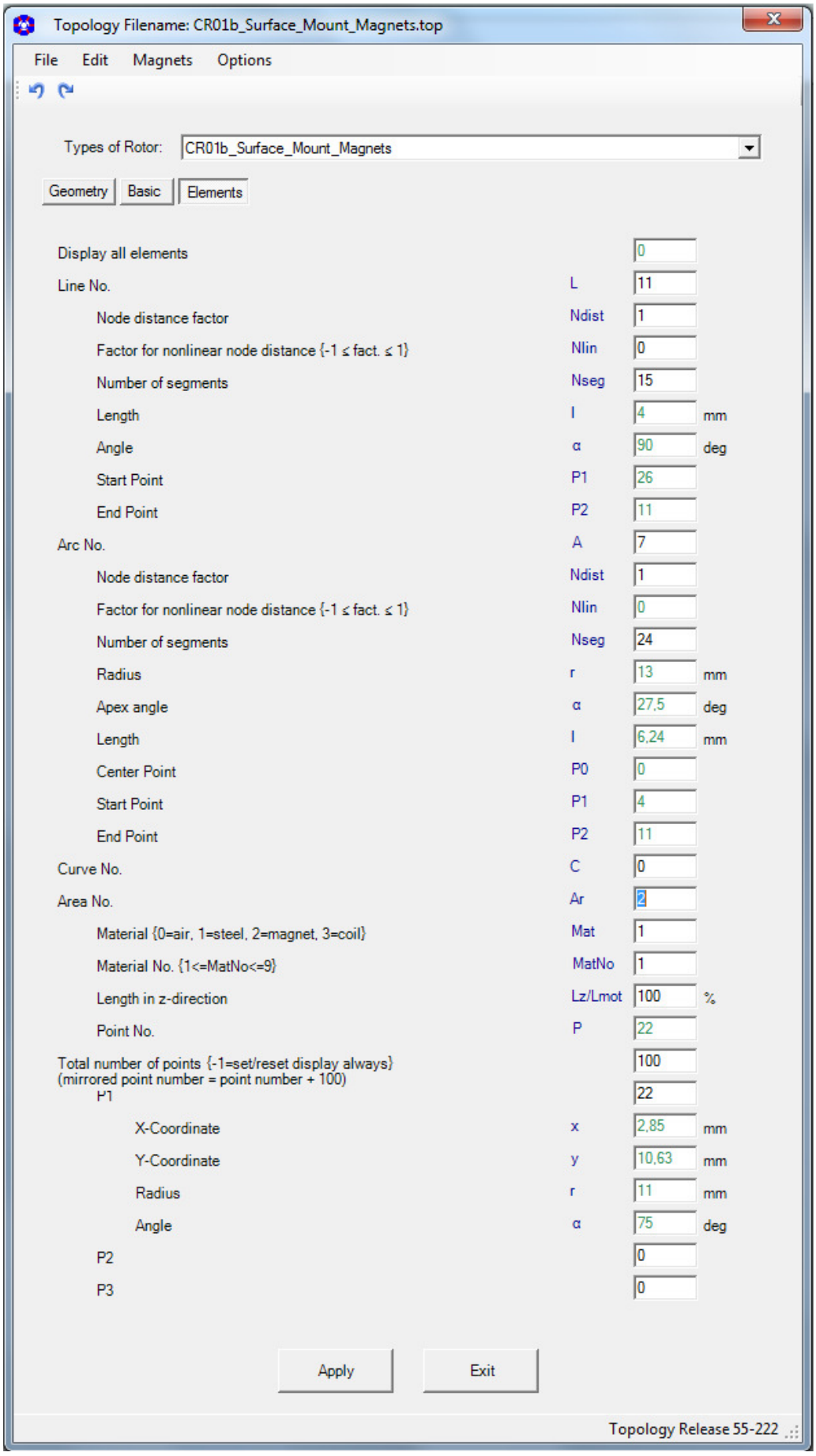
Additionally for certain topologies:

NccType = Type of the connection between geometry and outer airgap layer at left and right border of the complete model (none, line, closed area).

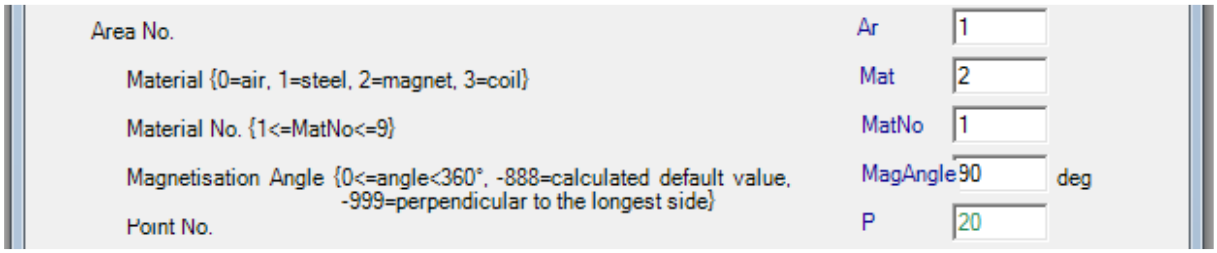


1.7.3 Parameter in group „Elements“

All Topologies



For areas which are defined as „Magnet“ (Mat=2) is the parameter „Ma*gAngle“* displayed. It indicates the direction of magnetization (north pole).

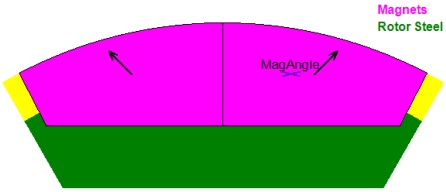


MagAngle can be changed:

- 0 <= MagAngle < 360°mech user defined

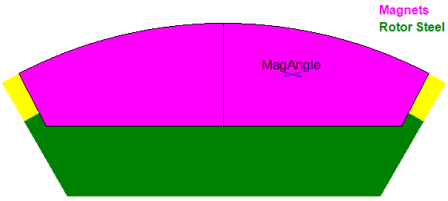
  Example

  MagAngle = 45°



- MagAngle = -999 direction of magnetization perpendicular to the longest side of the area.

  Example

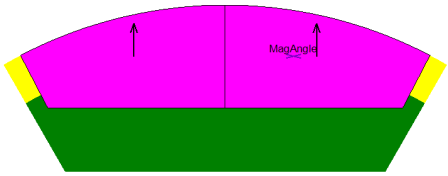


The vector is not displayed in the topology window but in the geometry window of smartFEM.

- MagAngle = -888 direction of magnetization as calulated by the topology (default value). After enter and apply of -888 is the calculated value displayed.

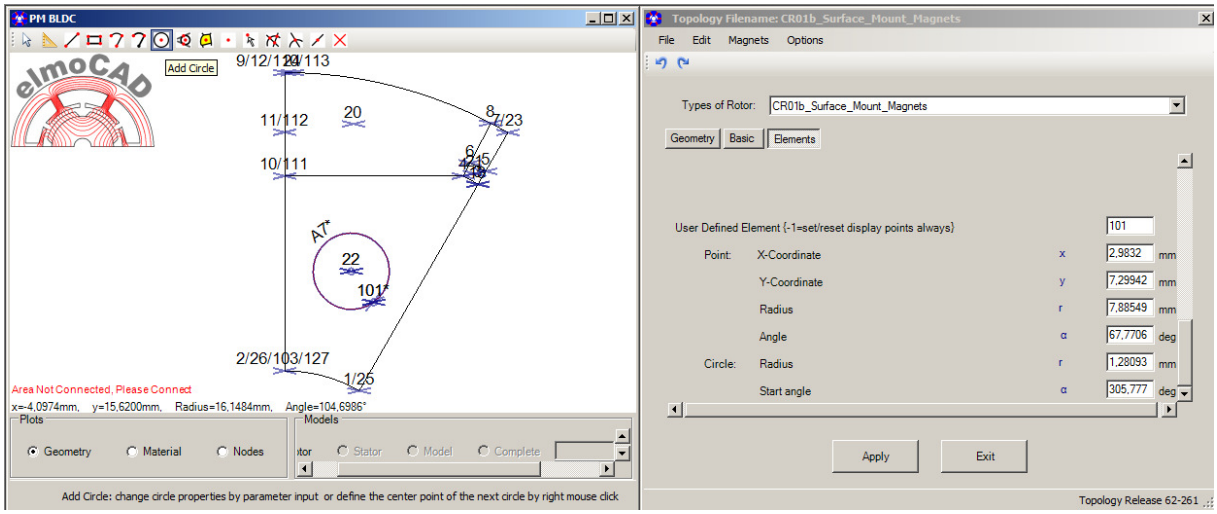
  Example

  calculated angle = 90°



1.8 User defined elements

For extension respectively change of geometries which are pre-defined by the topology algorithms a set of ***„ToolTipButtons“*** is displayed when the topology is opened (except of those topologies for dxf import). The selection of the ToolTipButtons is done by using the **left** mouse button. After that is the geometry displayed as non-mirrored. This view can also be selected via ***“Options”*** for all views. To add or select geometry elements the **right** mouse button then has to be used. A text for the next possible user actions is displayed in the status line.



Following modes and ToolTipButtons are available:

„Select Mode“ default mode after opening of a topologie

	„Select Mode“	→	leave „Edit Mode“, if selected before
	„Measure Distance Between Points“	→	measurement of the distance between two positions selected with right mouse button.

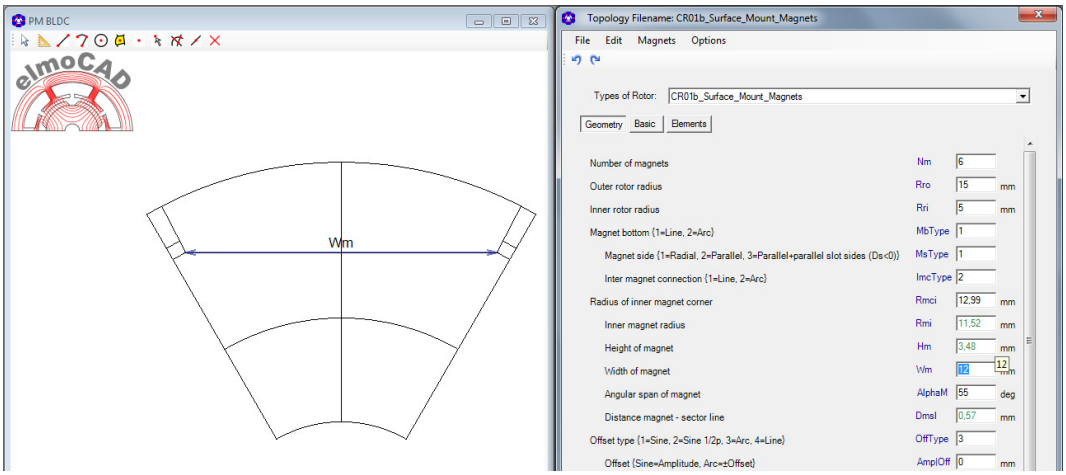
„Edit Mode“ after selection of one of the following ToolTipButtons

	„Add Line“	→	add a line
	„Add Rectangle“	→	add a rectangle
	„Add Arc“	→	add an arc (Pcen, Psta, Pend)
	„Add Arc“	→	add an arc (Psta, Pend, Radius)
	„Add Circle“	→	add a circle
	„Add Tangent Circle“	→	add a tangential circle (between line-line, line-arc or arc-arc)
	„Add Area“	→	add a point for definition of the material which is assigned to the area in which the point is positioned
	„Add Point“	→	add a point
	„Select Point“	→	select a point in order to change its xy-coordinates

	„Split All Intersections“	→	split all arcs and lines at their intersection points
	„Split Element at Intersection“	→	split one element at its intersection
	„Split Element At Mouse Position“	→	split an element at mouse position
	„Delete Element“	→	delete an element.

1.8.1 Use of „Edit Geometry“

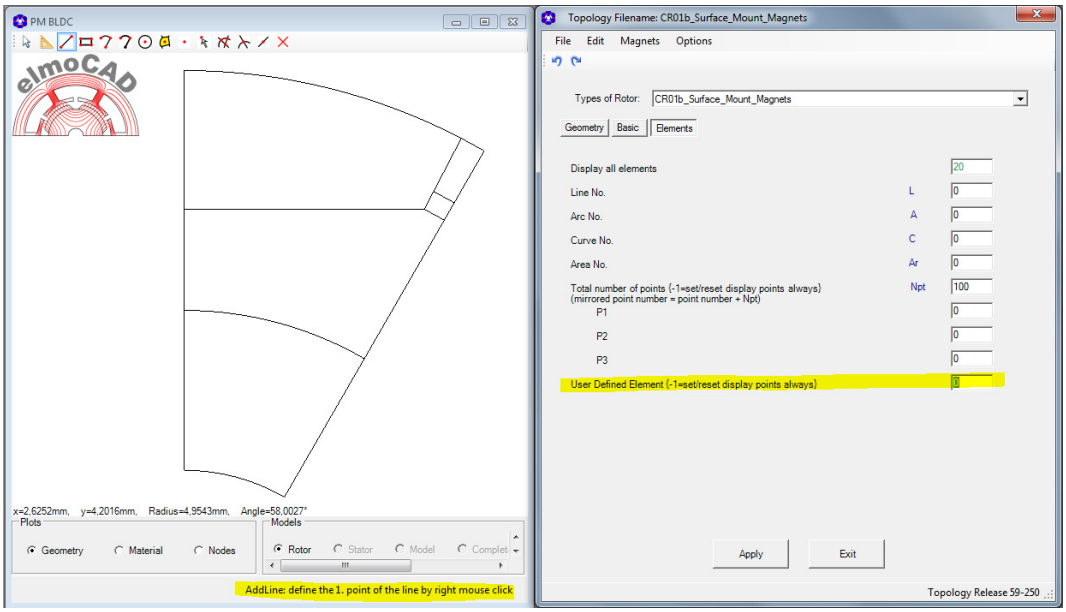
- Every topology is opened in ***„Select Mode“*** and as in all previuos smartFEM releases all functions for selection and handling of drawing elements and parameter are available.



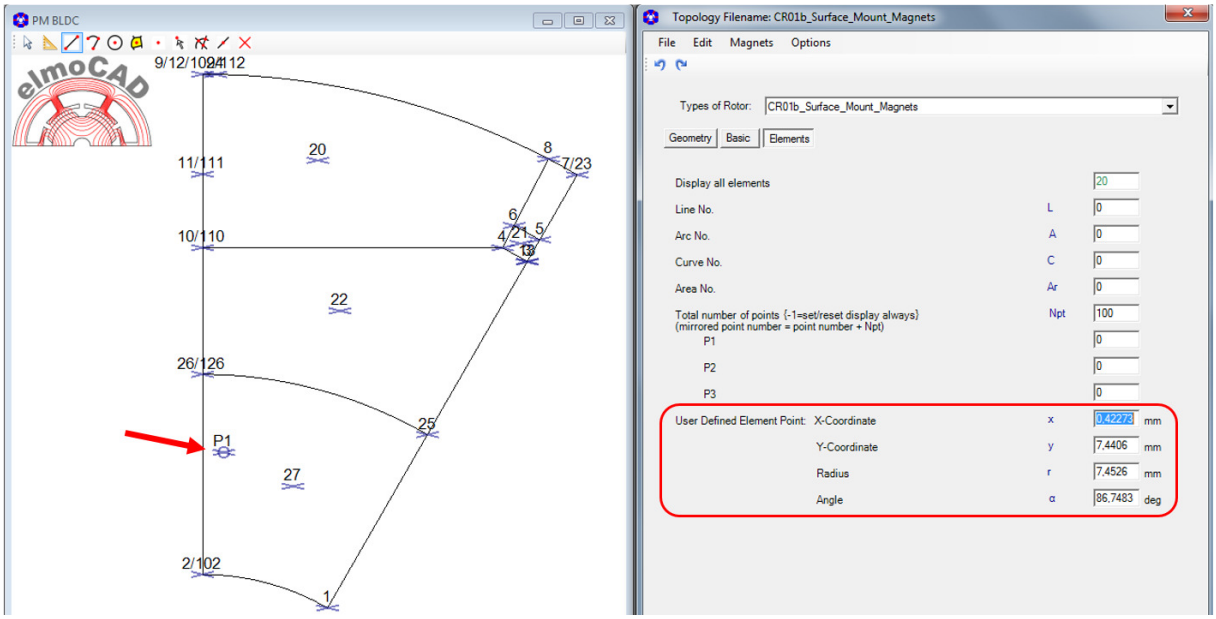
- The ToolTopButtons can be activated by click with the left mouse button on it. The non-mirrored geometry (half pole if designed) will be displayed.

  Example: ***„AddLine“***

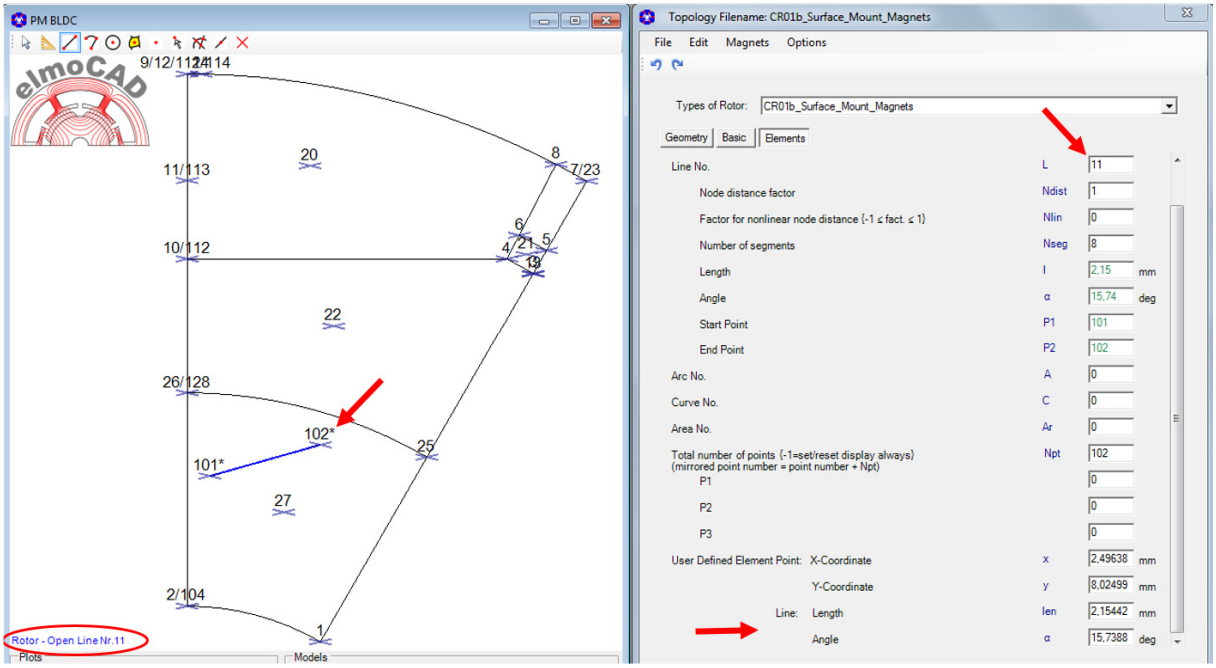
  Display of the non-mirrored geometry. Simultaneously is the parameter group ***“Elements”*** with an additional parameter is opened for the later adjustment of xy-coordinates and further parameter. Additionally a help text is displayed in the bottom line which indicates the next possible actions for adding the line.



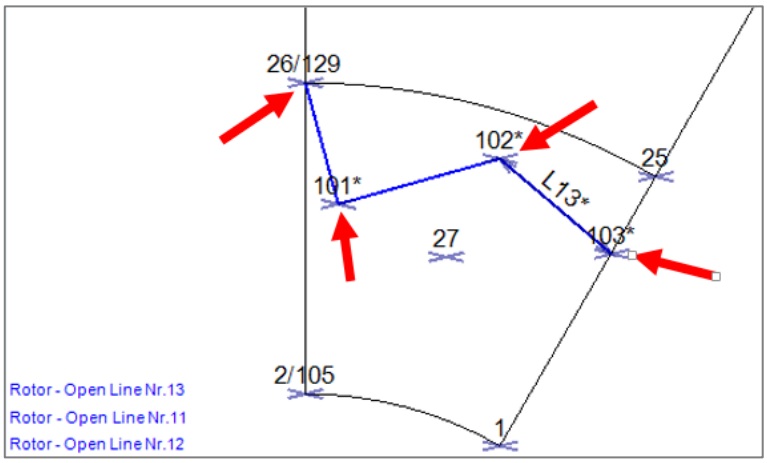
- For editing of the geometry the right mouse button has to be used.
- The definition of the starting point of the line is carried out at the position of the mouse pointer by click with the right mouse button. The point is marked by “P1”. The cartesian and polar coordinates of the point are displayed in the list of parameters and can be exactly adapted to the wanted position by numerical input values.



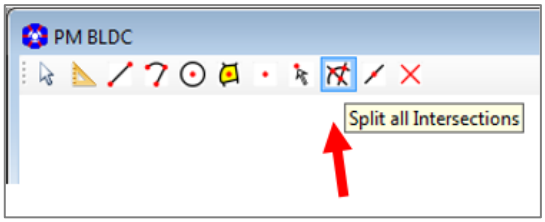
- Next the end point of the line can be defined by right mouse click. Now the properties of the line and information if it is possible open or has intersections are displayed. Length and angle of the line can be adapted by parameter input (same as like start point).

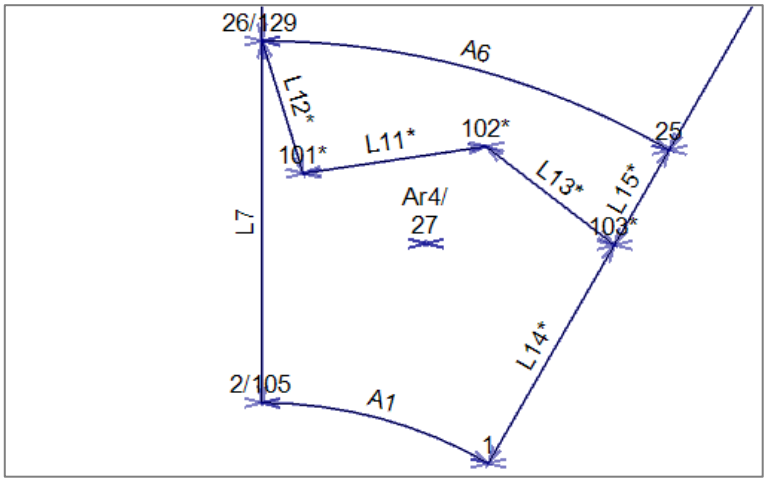


- If further lines are added and with that positions on other drawing elements are selected, then the „snap function“ will be activated and the xy-coordinates are recalculate in such a way that the point lies exactly on the selected element.



In this case is the total polyline (points 26-101-102-102) onlay connected by point 26 to the geometry. The line between point 1 and 25 has to be splitted at point 103. For this the ToolTipButton ***“Split All Intersections”*** can be used.



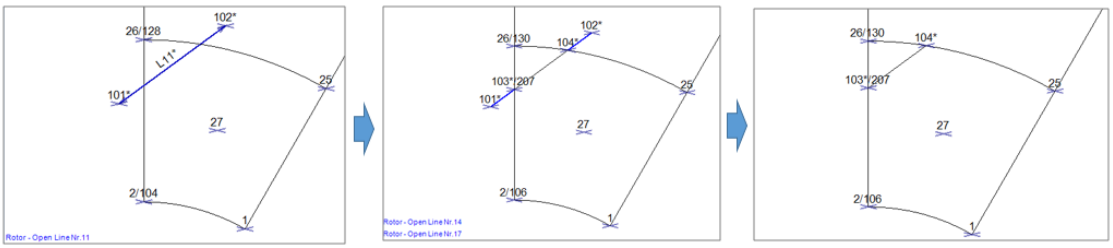


or i.e.

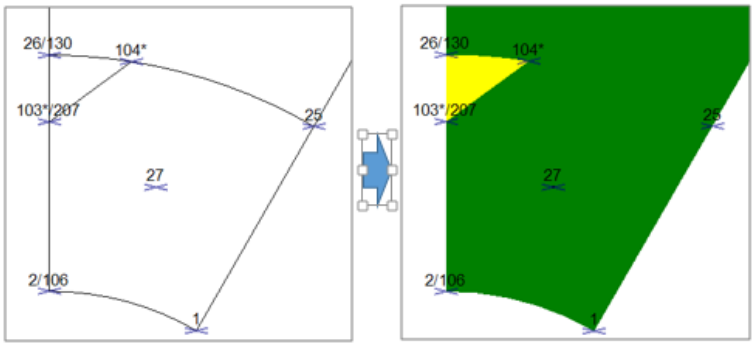
new line with intersections

“Split All Intersections” → 2 open lines arise

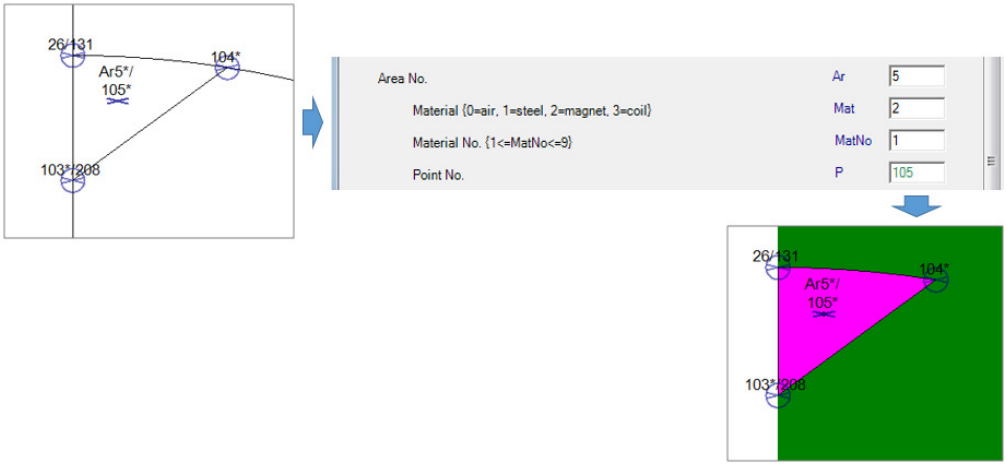
consistent geometry after the open lines are deleted



In „Material“ view the new triangle area is displayed as „air“.

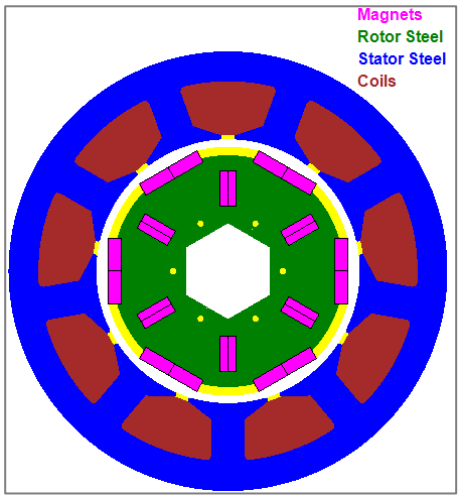


- By ToolTipButton ***„Add Area“*** the triangle area can be defined as parametrizable area element and after that other material than “air” can be selected.



- Working with arc, circles and free points are done analogous lines.

Example: additional holes and magnets in rotor topology „CR01_Surface_Mount_Magnets”



Other ToolTipButtons:

„Select Point“	for adaption of xy-coordinates respectiveley radii and angle of user defined points.
„Split All Intersections“	split all arcs and lines at all intersections.
„Split Element At Intersection“	split single arcs and lines at intersections.
„Split At Mouse Position“	split single arcs and lines at mouse position.
„Delete Element“	delete elements defined by user or topology.

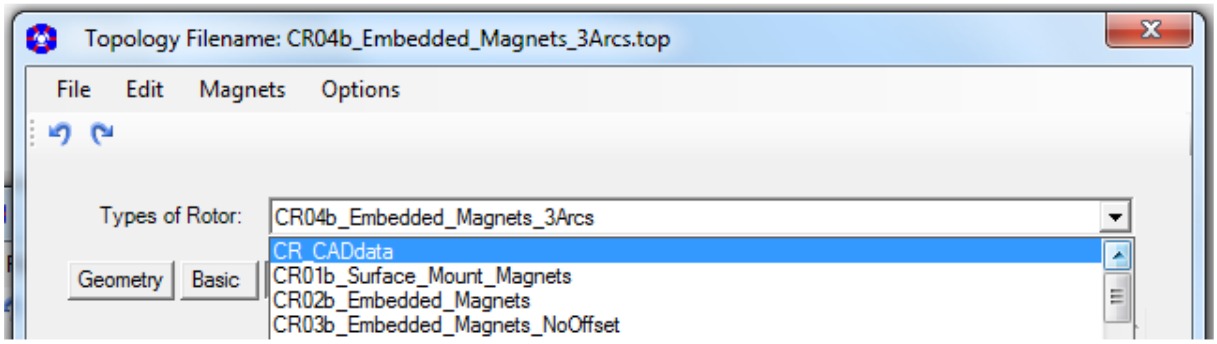
2 Topologien

2.1 DXF-Import

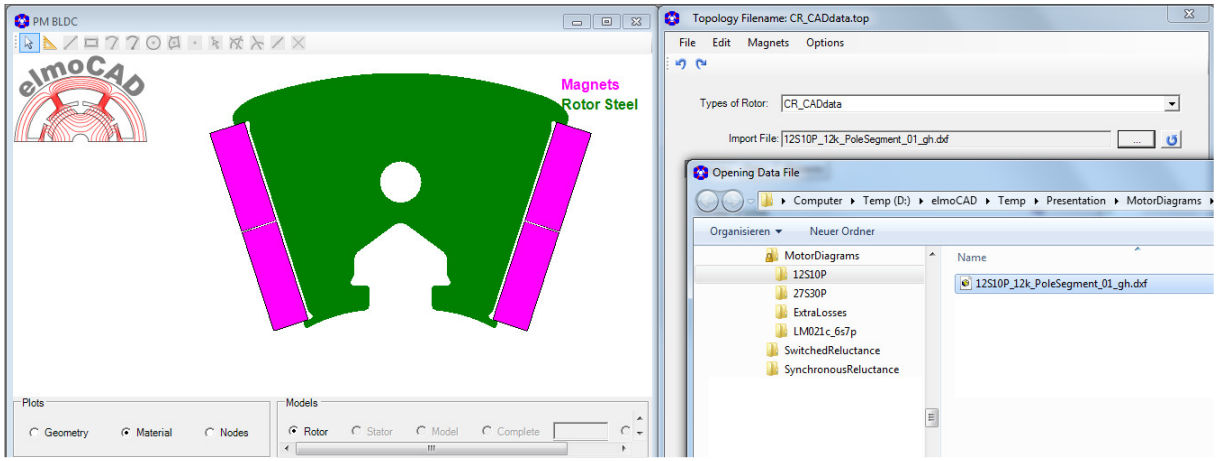
For the import of rotor and stator geometries created by users in CAD systems are per machine model one topology *"xx-CADdata.top"* respectively *"LM_CADdata.tol"* available. A detailed description is documented in the smartFEM UserGuide.

Example: DXF-import of a rotor geometry

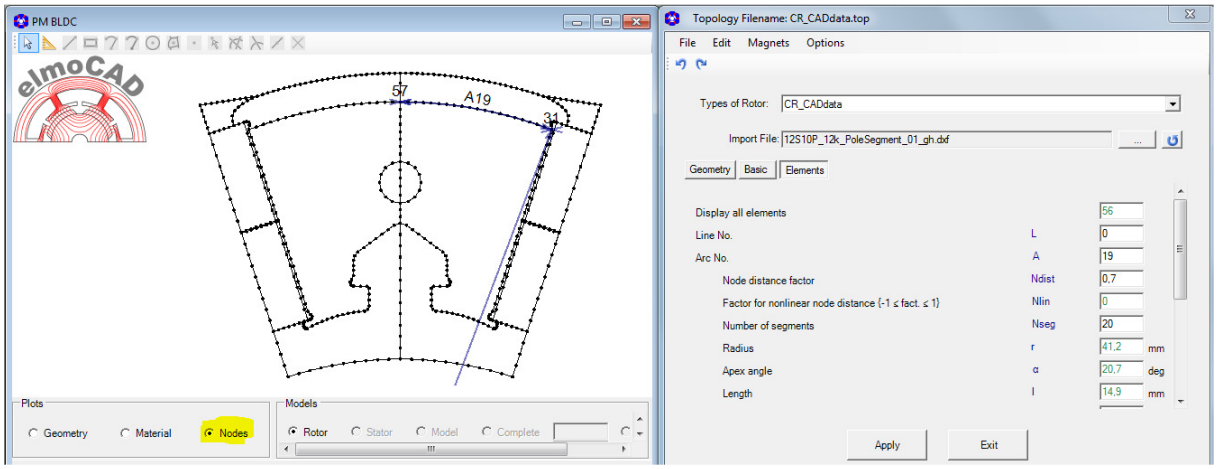
Step 1: selection of the rotor topology *"CR_CADdata"*



Step 2: selection of the DXF-formatted file which was created by a CAD system and contains the geometry data of the rotor.

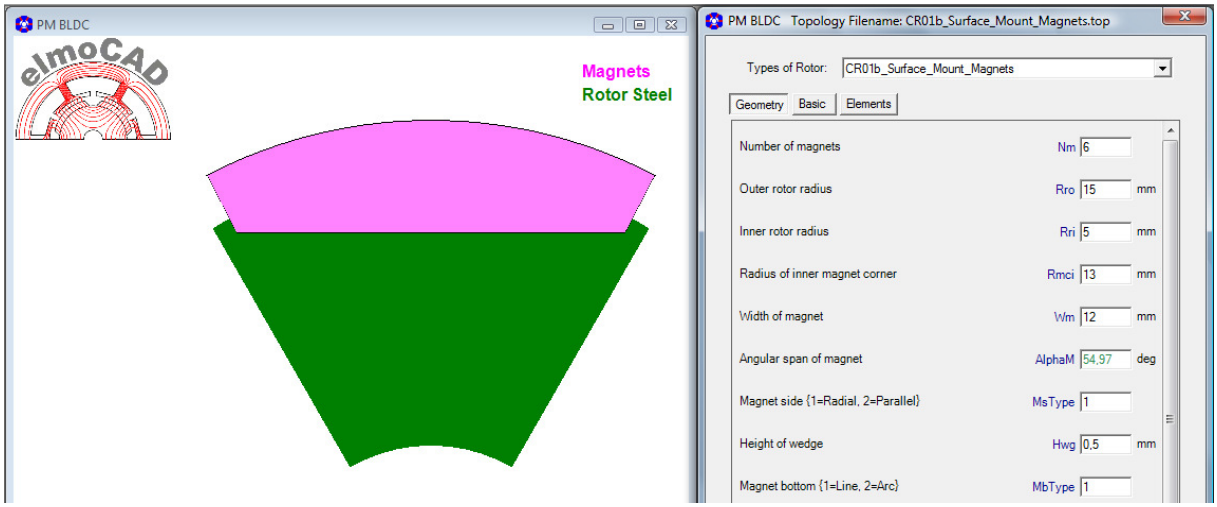


Step 3: if neccessary adaption of node chains and other parameter.



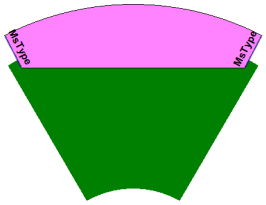
2.2 Inner Rotor Topologies

2.2.1 CR01b_Surface_Mount_Magnets

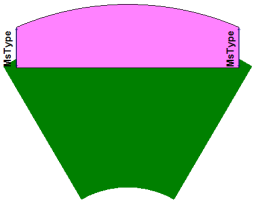


Possible geometries as result of parameter changes

Magnet Side:

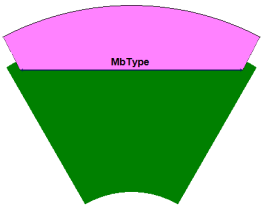


radial

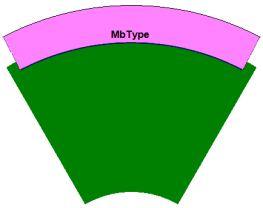


parallel

Magnet Bottom:

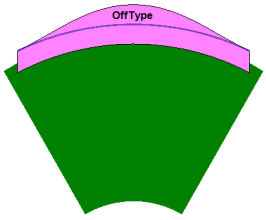


Gerade

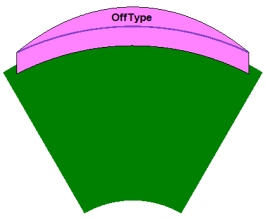


Kreisbogen

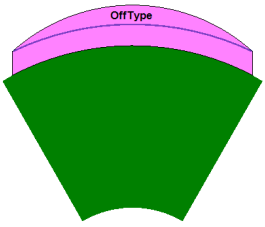
Offset Type:



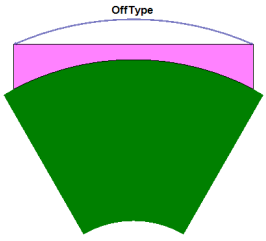
Sinus 1 Period



Sinus ½ Period

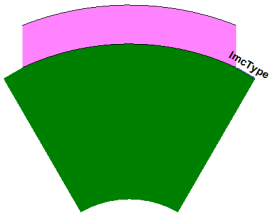


Arc

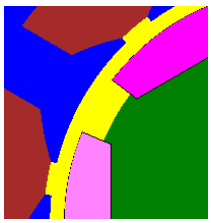


Line

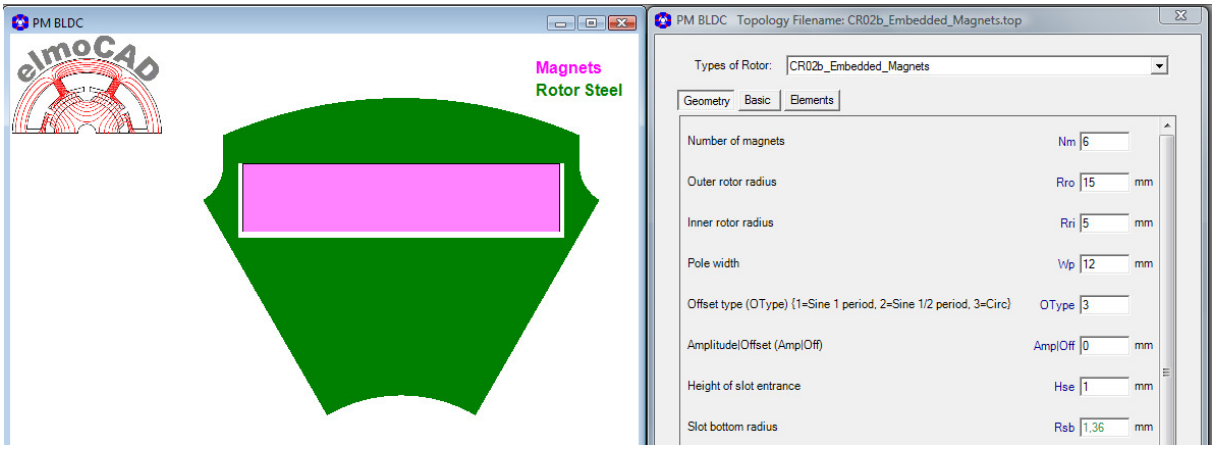
Connection Magnet-Magnet:



Line or Arc

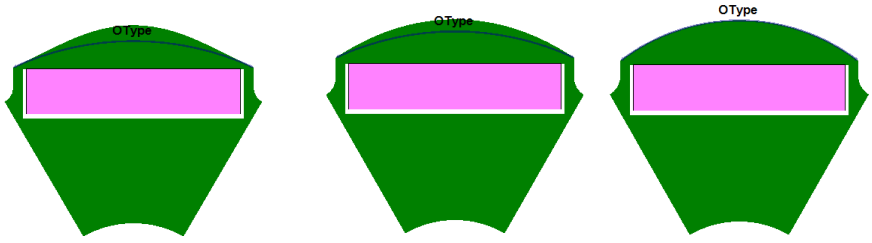


2.2.2 CR02b_Embedded_Magnets



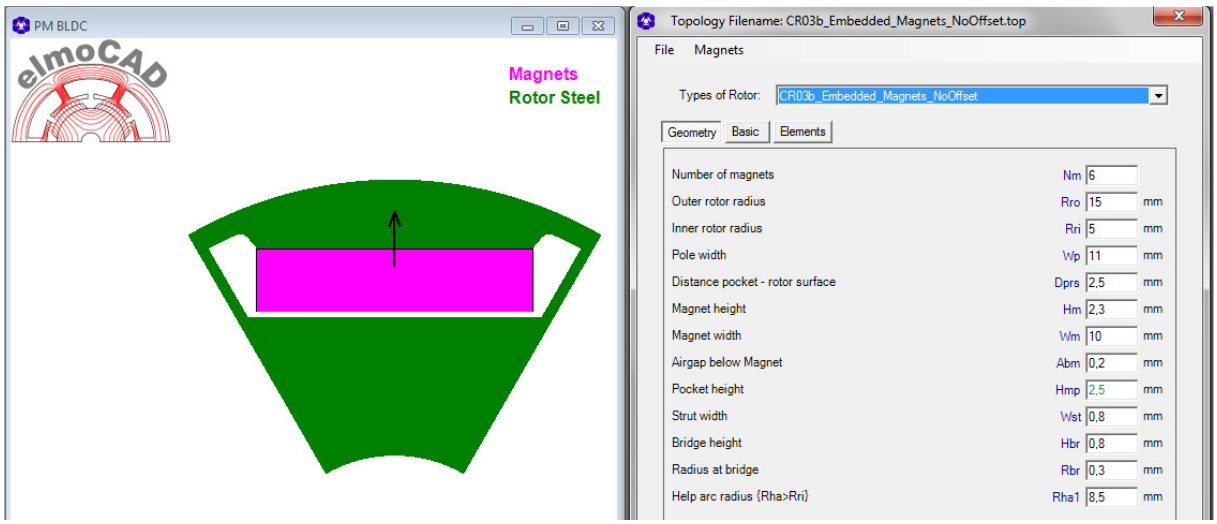
Possible geometries as result of parameter changes

Offset Type:

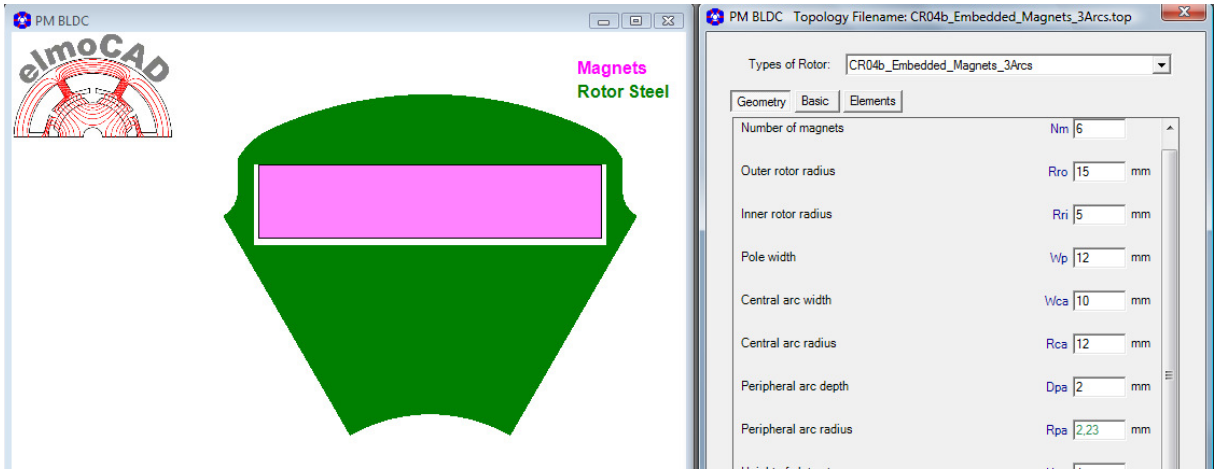


Sinus 1 Period | Sinus ½ Period | Arc

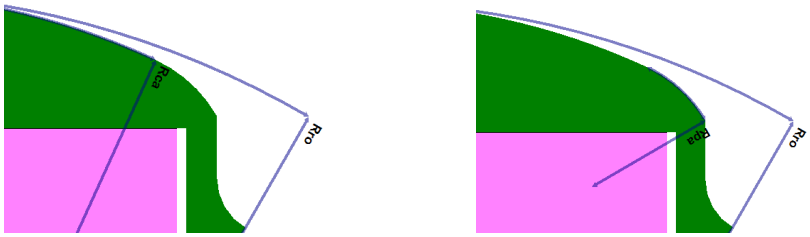
2.2.3 CR03b_Embedded_Magnets_NoOffset



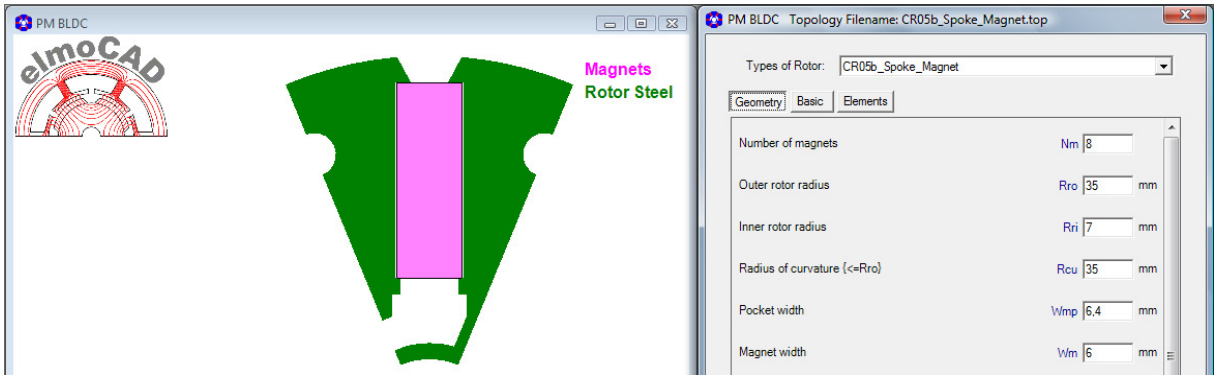
2.2.4 CR04b_Embedded_Magnets_3Arcs



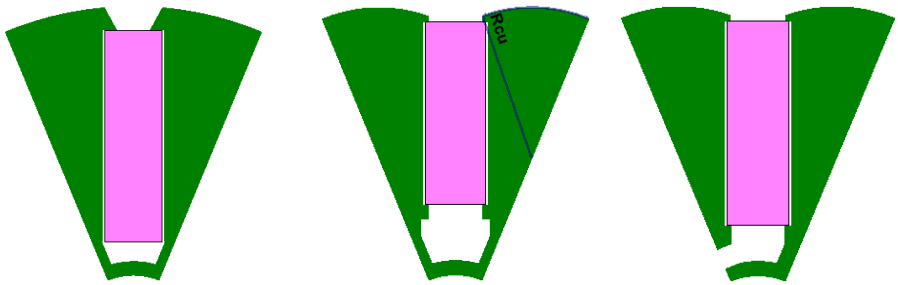
The rotor surface is modelled by 3 arcs, 1 central arc and 2 periphal arcs (one on each left/right side).



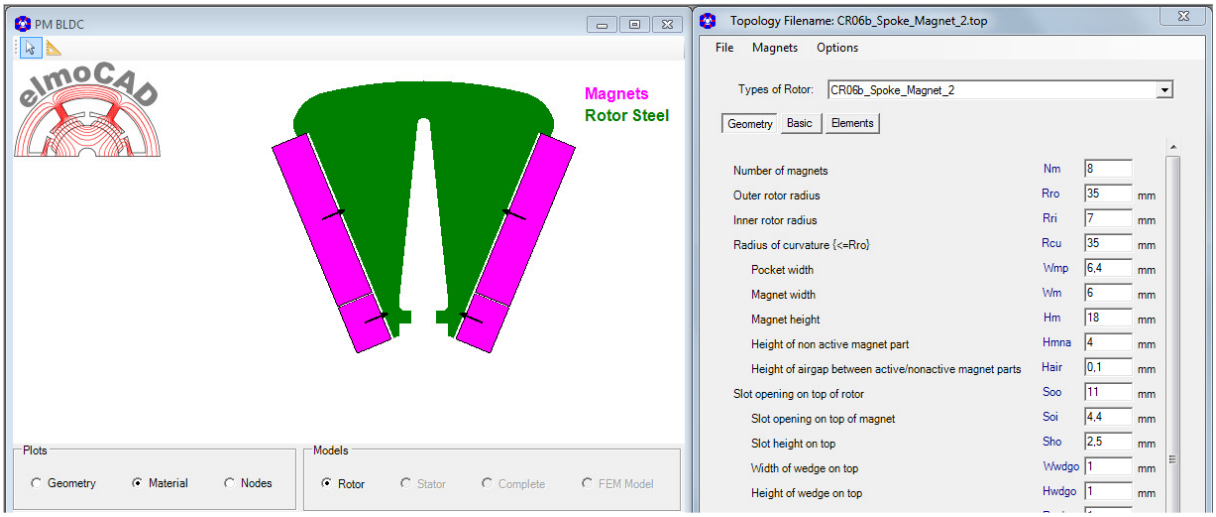
2.2.5 CR05b_Spoke_Magnet



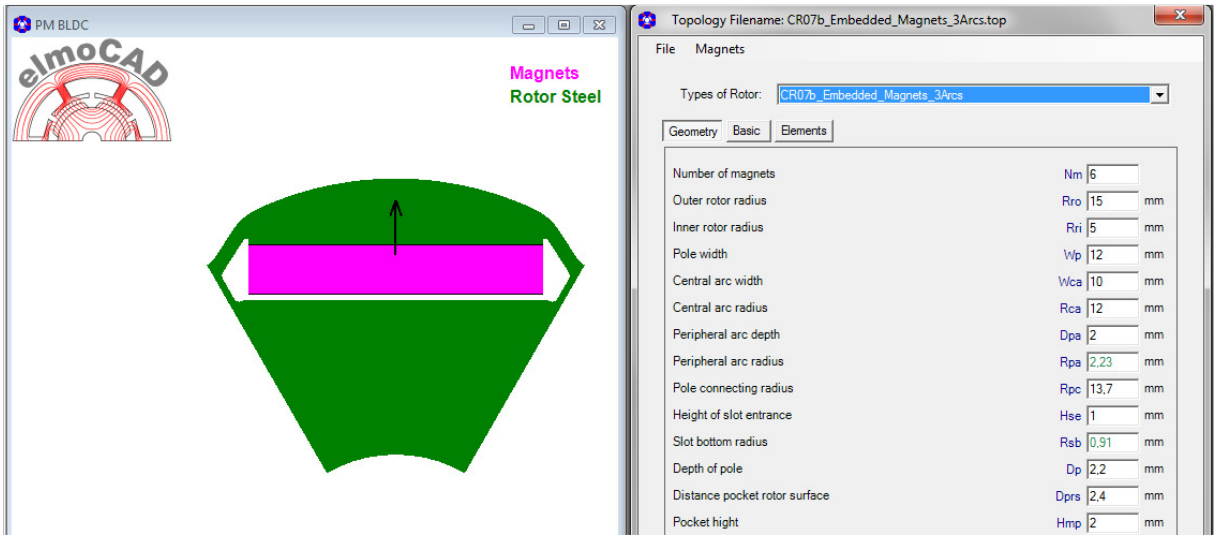
Possible geometries as result of parameter changes:



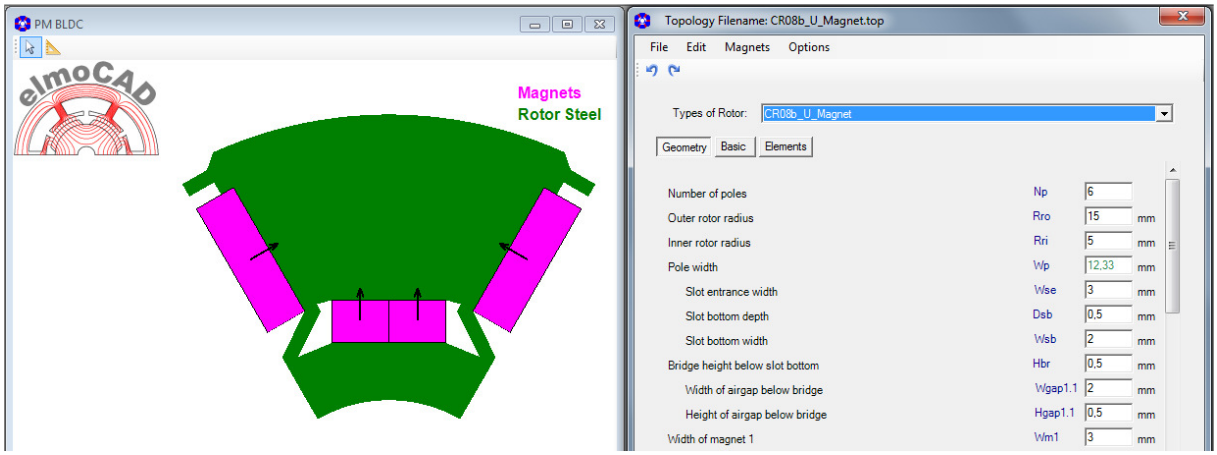
2.2.6 CR06b_Spoke_Magnet_2



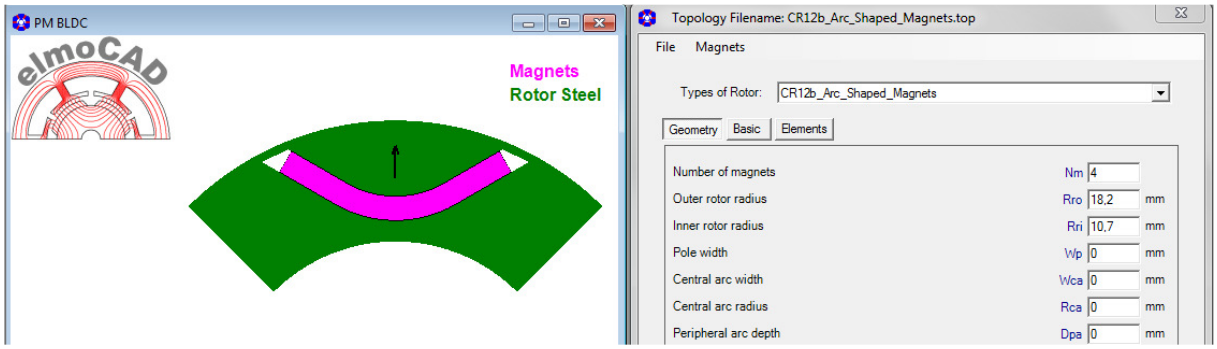
2.2.7 CR07b_Embedded_Magnets_3Arcs



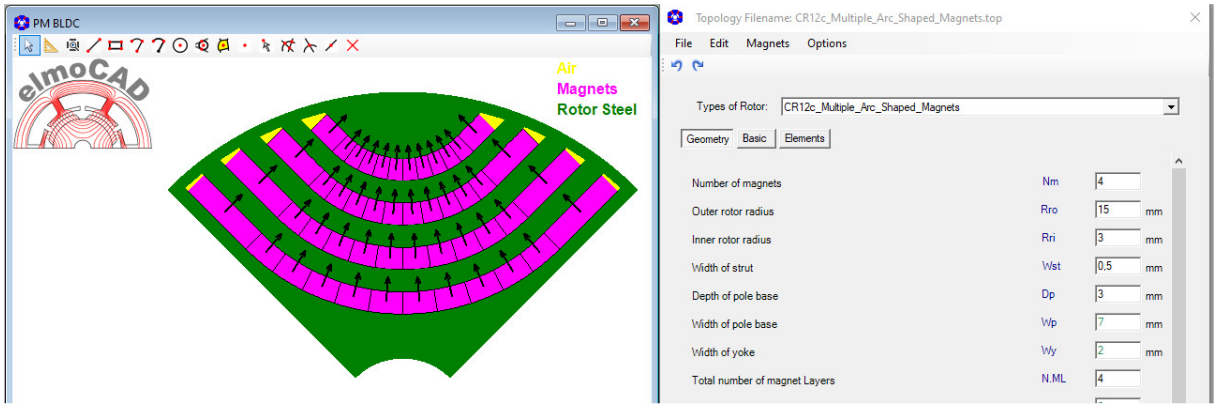
2.2.8 CR08b_U-Magnet



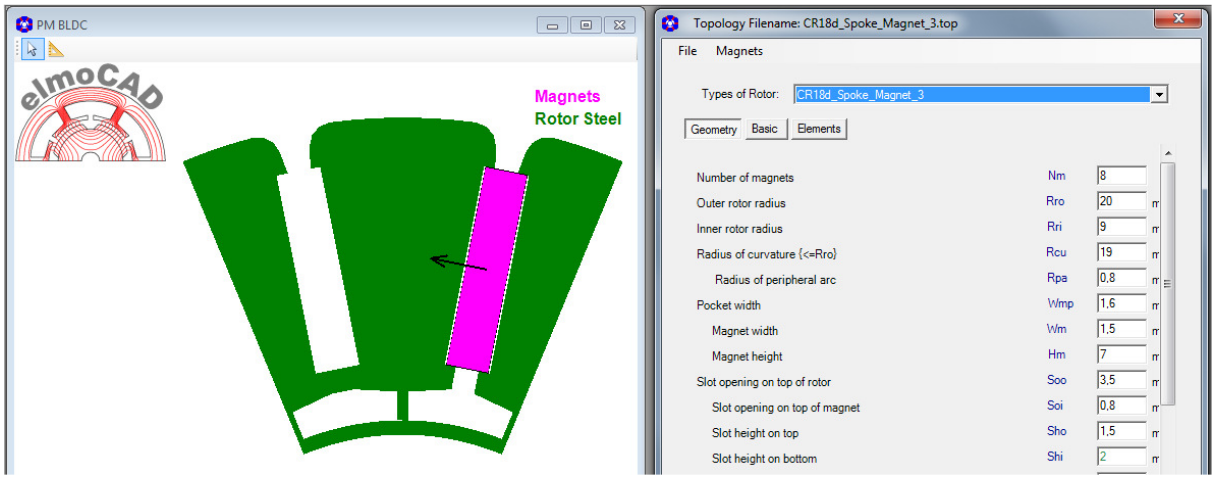
2.2.9 CR12b_Arc_Shaped_Magnets



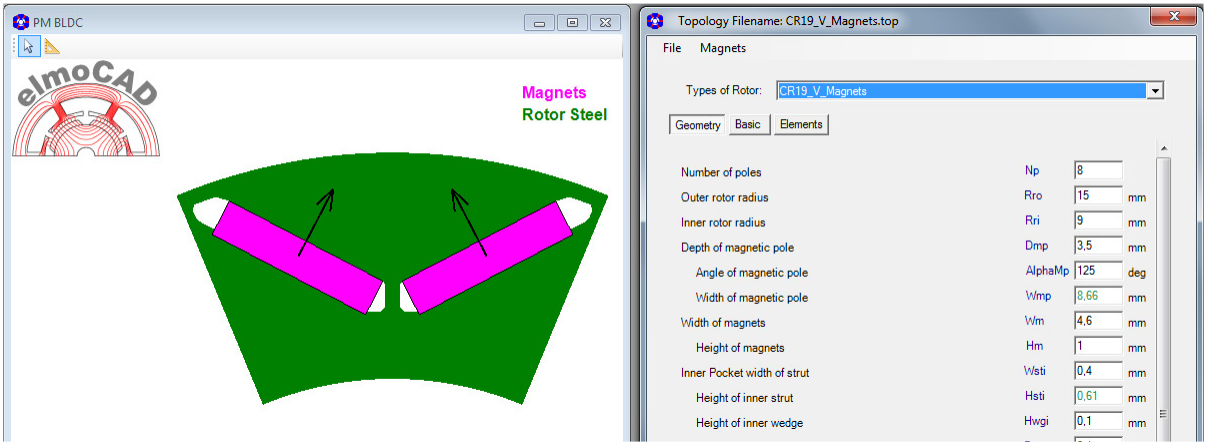
2.2.10 CR12c_Multiple_Arc_Shaped_Magnets



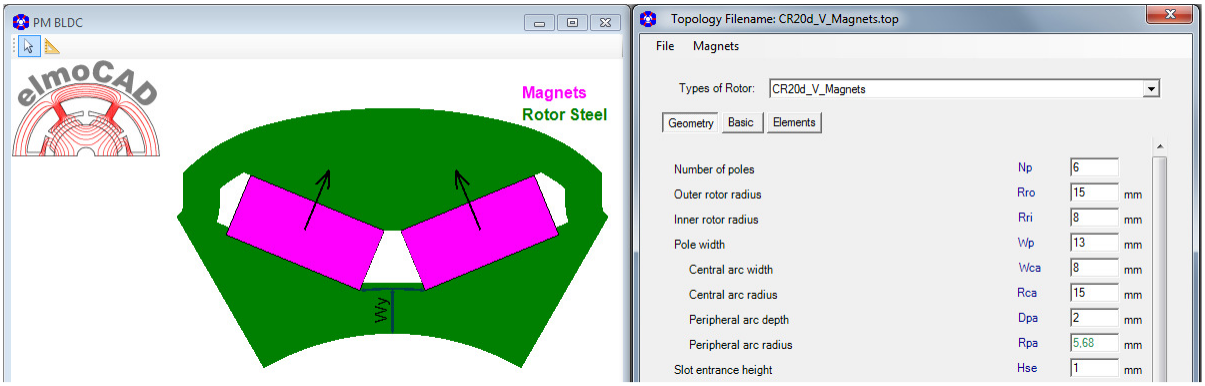
2.2.11 CR18d_Spoke_Magnet_3



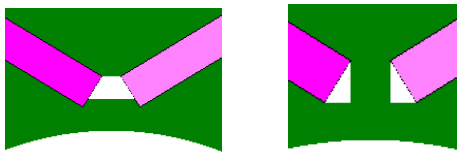
2.2.12 CR19_V_Magnets



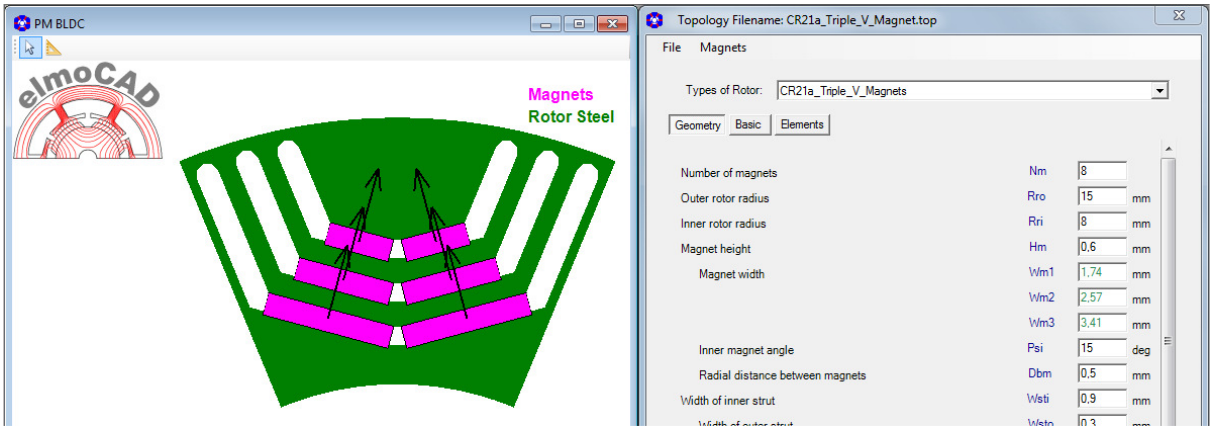
2.2.13 CR20d_V_Magnets



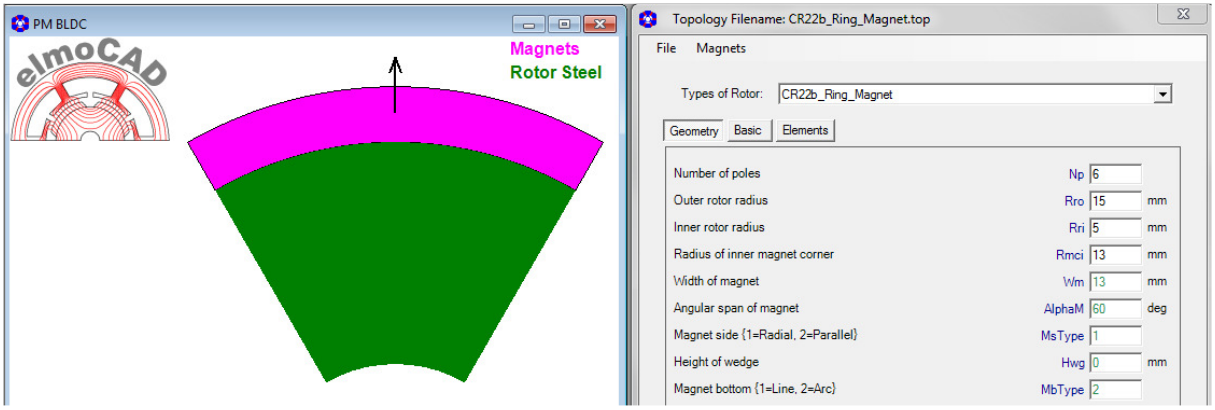
Possible with or without bar between the magnets



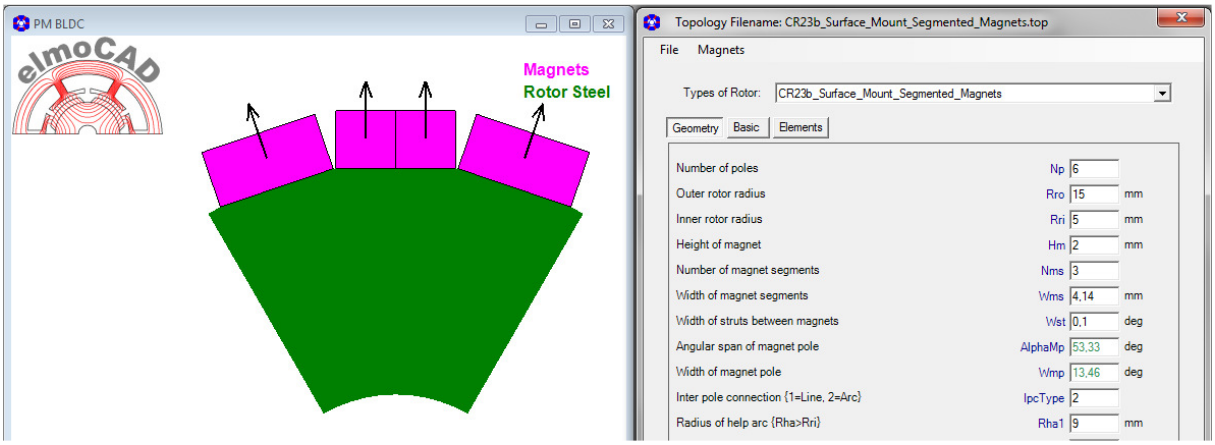
2.2.14 CR21a_Triple_V_Magnets



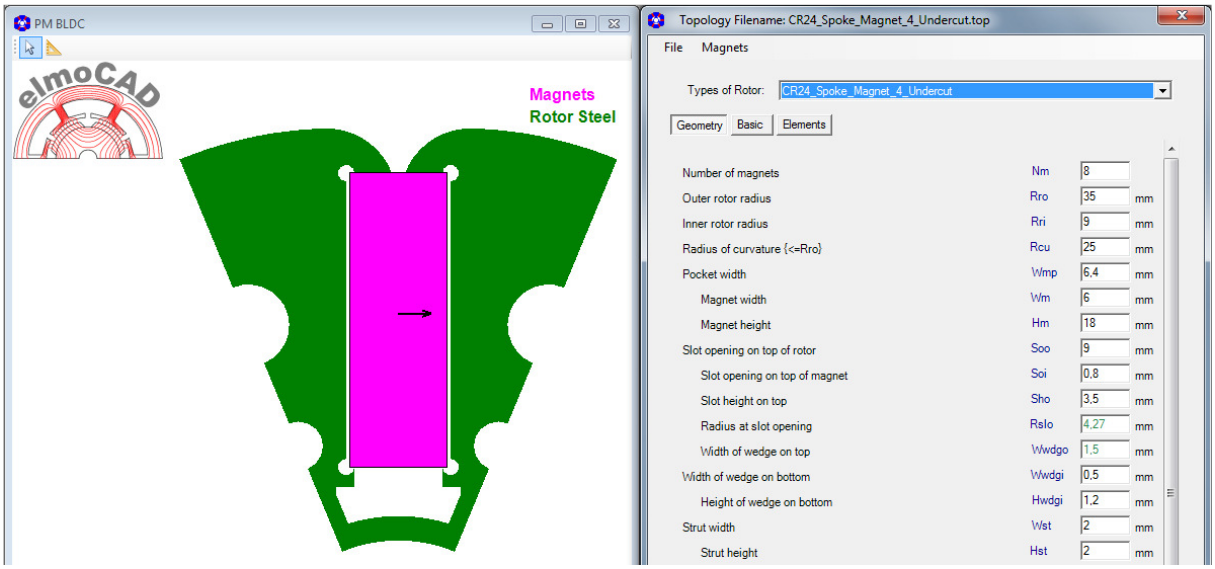
2.2.15 CR22b_Ring_Magnet



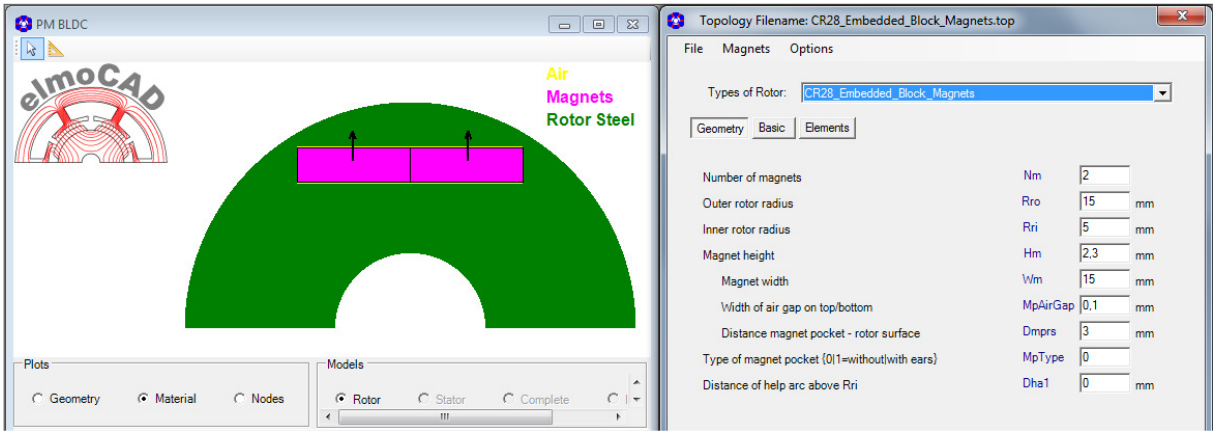
2.2.16 CR23b_Surface_mount_Segmented_Magnets



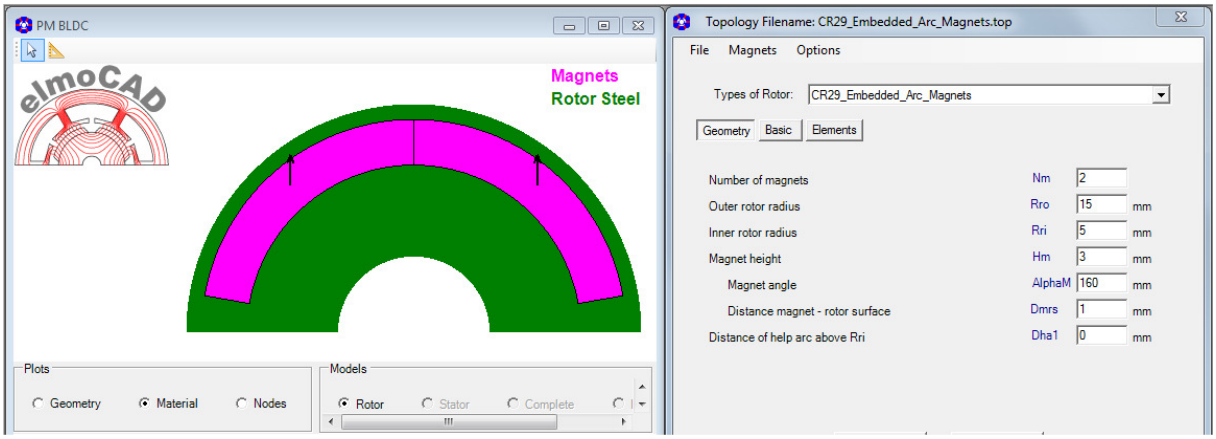
2.2.17 CR24_Spoke_Magnet_4_Undercut



2.2.18 CR28_Embedded_Block_Magnets

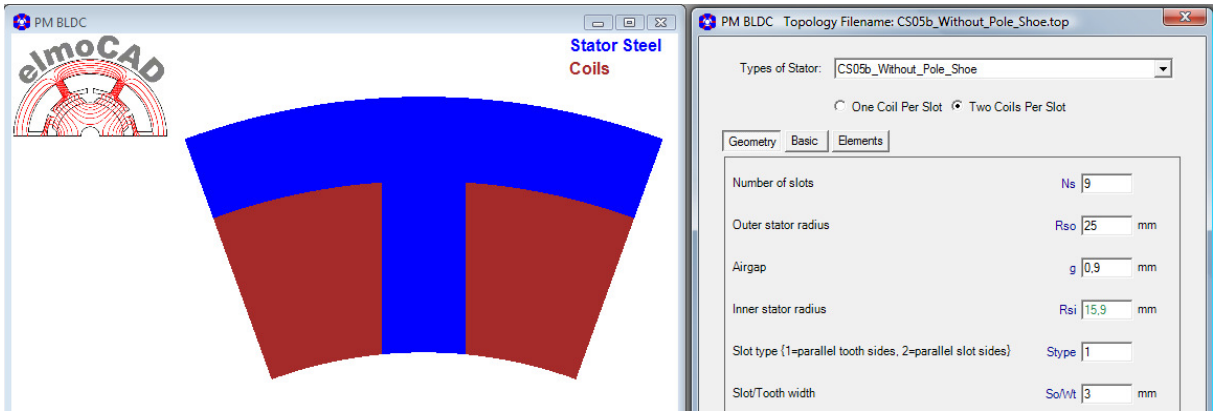


2.2.19 CR29_ Embedded_Arc_Magnets

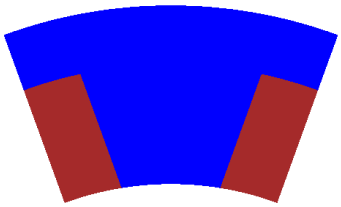


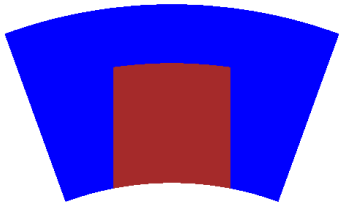
2.3 Stator Topologies for Inner Rotor Machines

2.3.1 CS05b_Without_Pole_Shoe

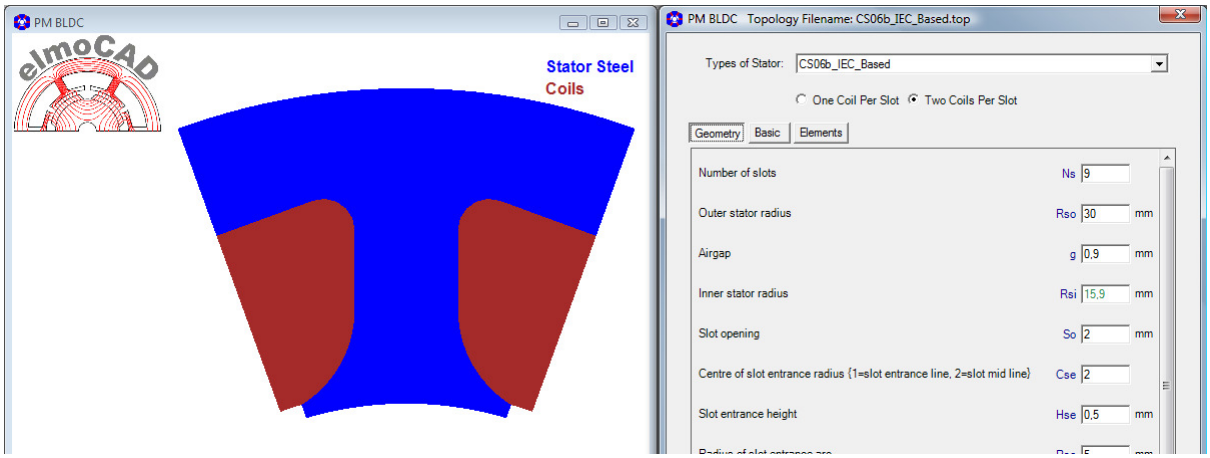


Possible with parallel tooth sides or parallel slot sides:



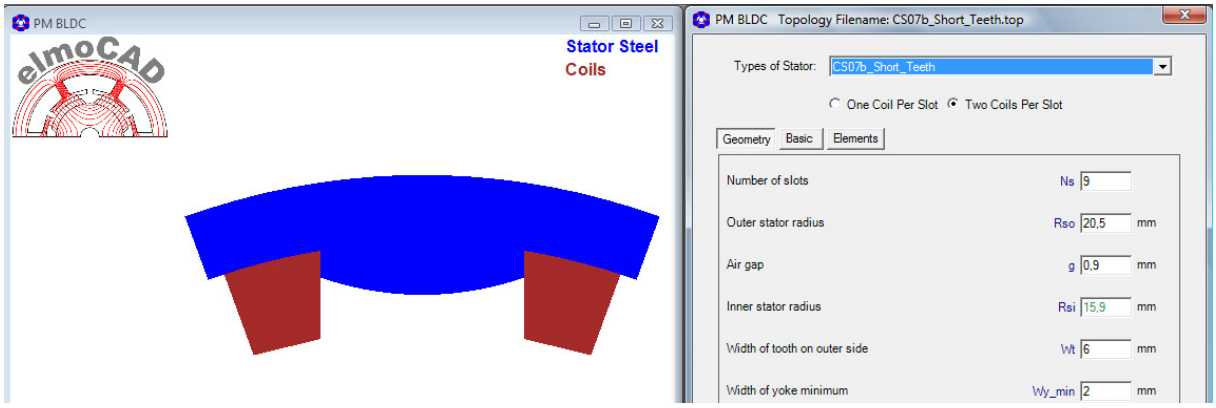


2.3.2 CS06b_IEC_Based

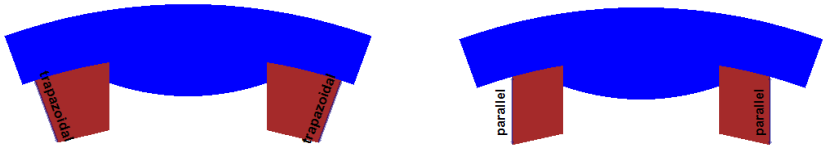


Dimensions of different IEC electric steel lamination catalogues can be applied.

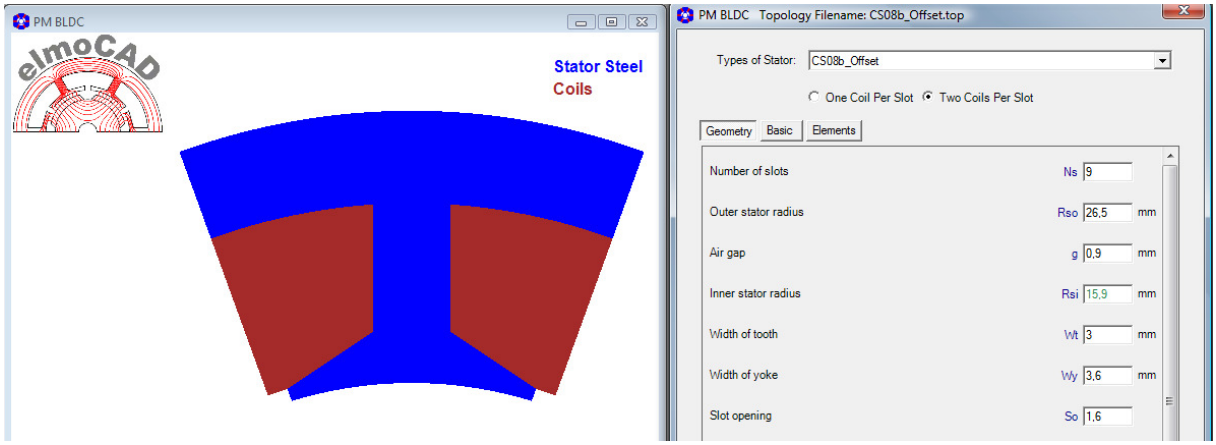
2.3.3 CS07b_Short_Teeth



Possible with trapezoidal / parallel sides of the windings

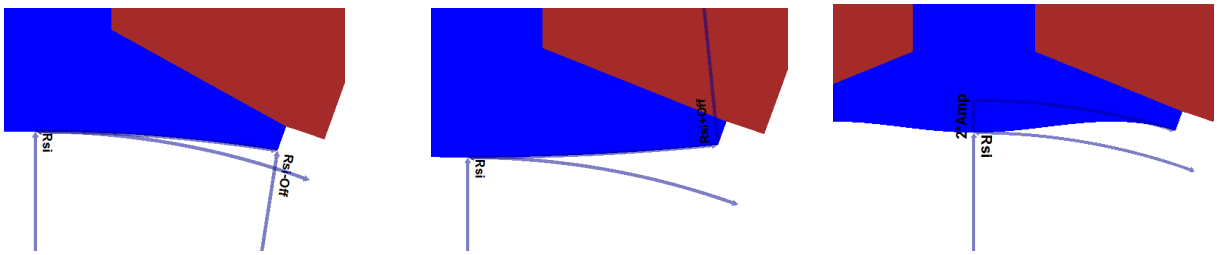


2.3.4 CS08b_Offset und CS08c_Offset



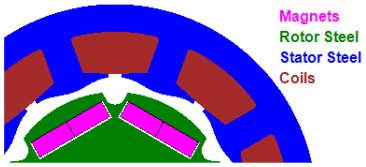
CS08c includes additonal properties compared to CS08b

Offset Type:

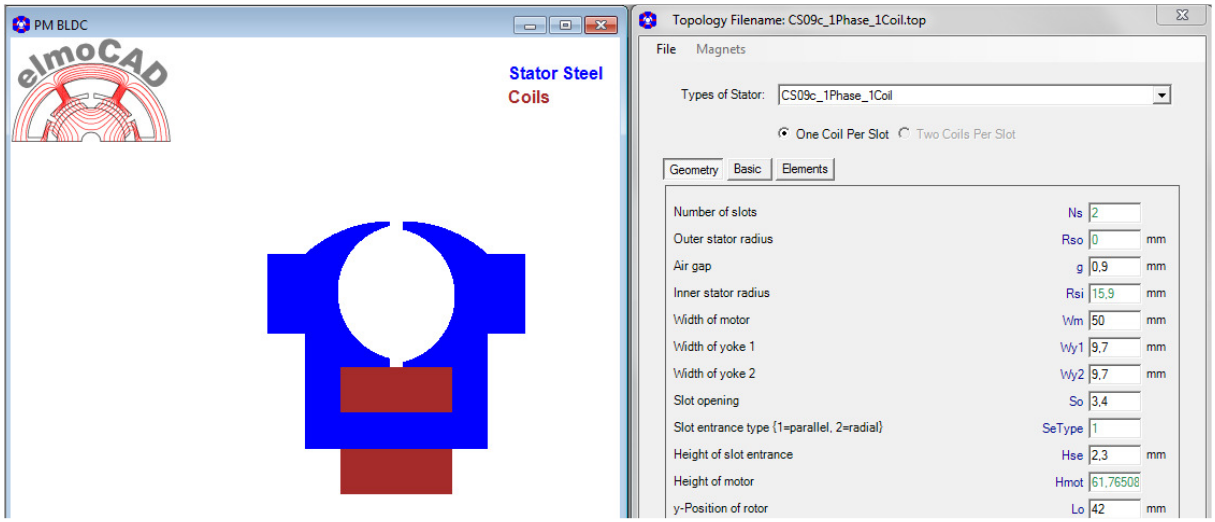


Convex arc concave arc Sinus 1 Period

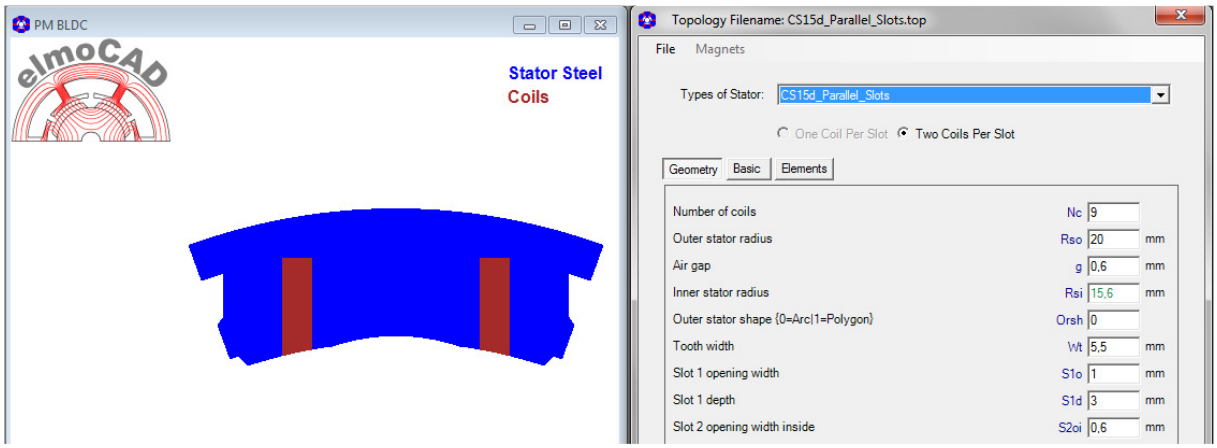
Example: representation of the machine geometry with sinusoidal offset of the pole shoes



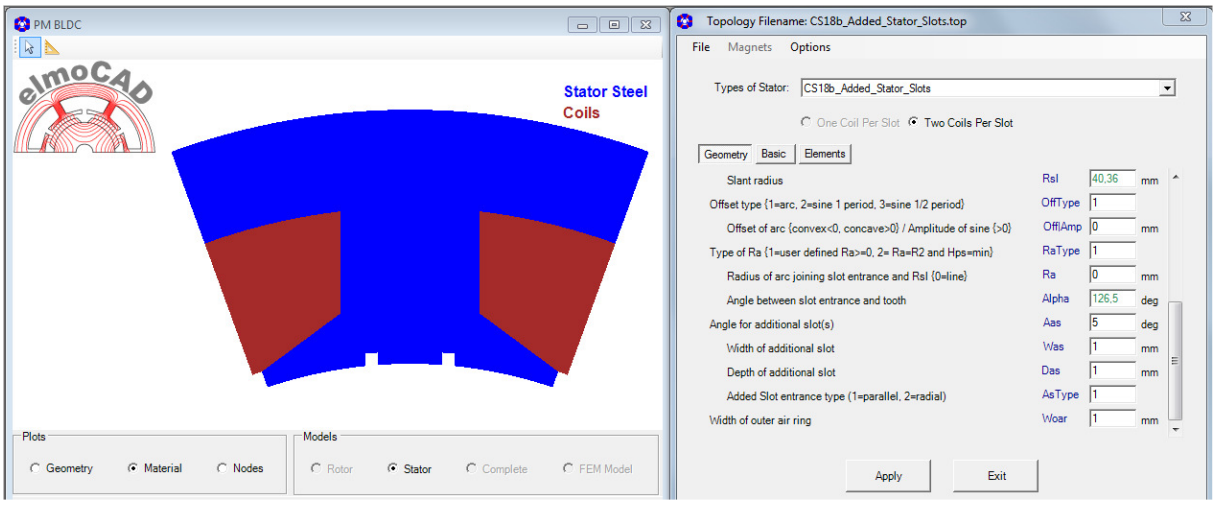
2.3.5 CS09c_1Phase_1Coil



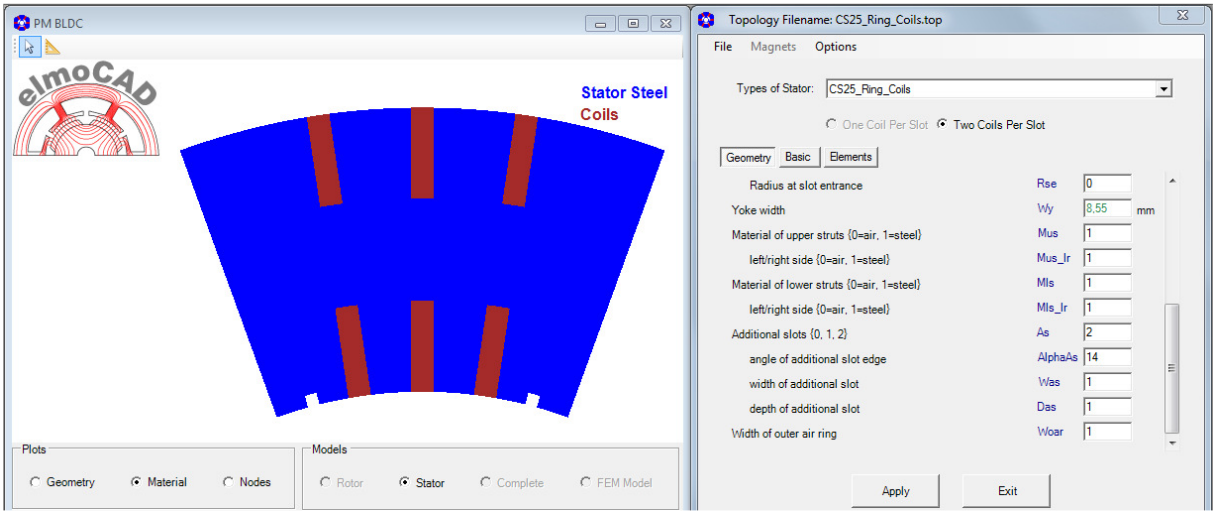
2.3.6 CS15d_Parallel_Slots



2.3.7 CS18b_Added_Stator_Slots

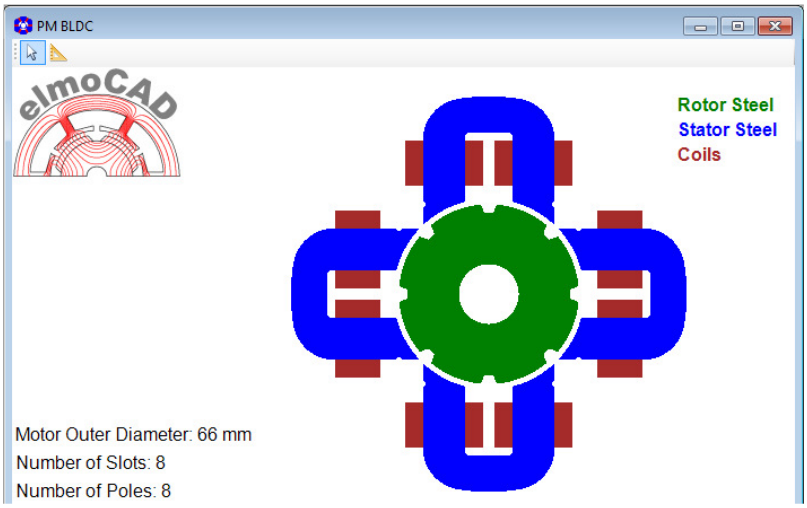


2.3.8 CS25_Ring_Coils



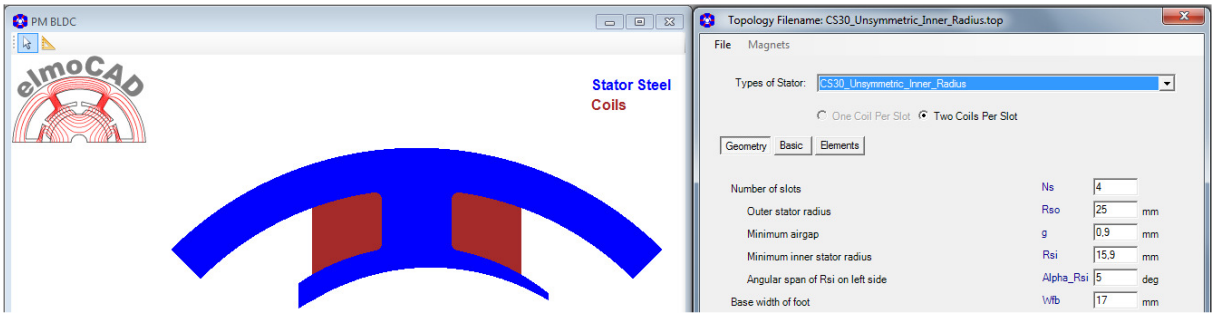
Possible with or without additional grooves at the airgap to reduce cogging torque

2.3.9 CS26_U_Pole_Shanks



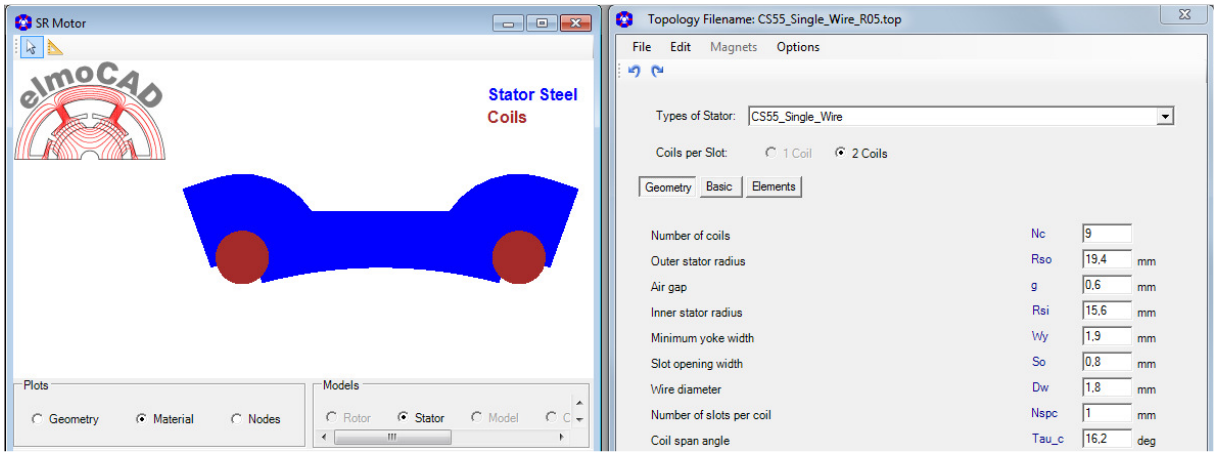
This is a special design of a Switched Reluctance Motor so called “Plusmotor” based on the patent EP 0 782 781 B1 (published 09.07.1997), which was analysed by Stefan Weber and documented in his “Diplomarbeit” (2002, Technical University of Ilmenau Germany).

2.3.10 CS30_Unsymmetric_Inner_Radius



For the design von 1 and 2phase motors

2.3.11 CS55_Single_Wire



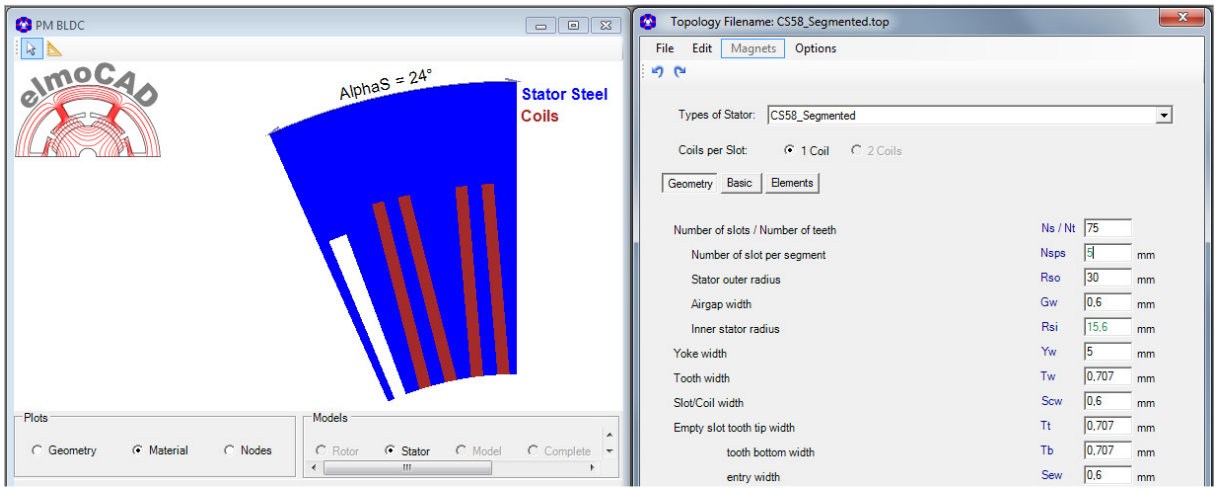
2.3.12 CS56_MGPM_1Airgap

Magnetic Geared PM Machine (2.11.1, page 45)

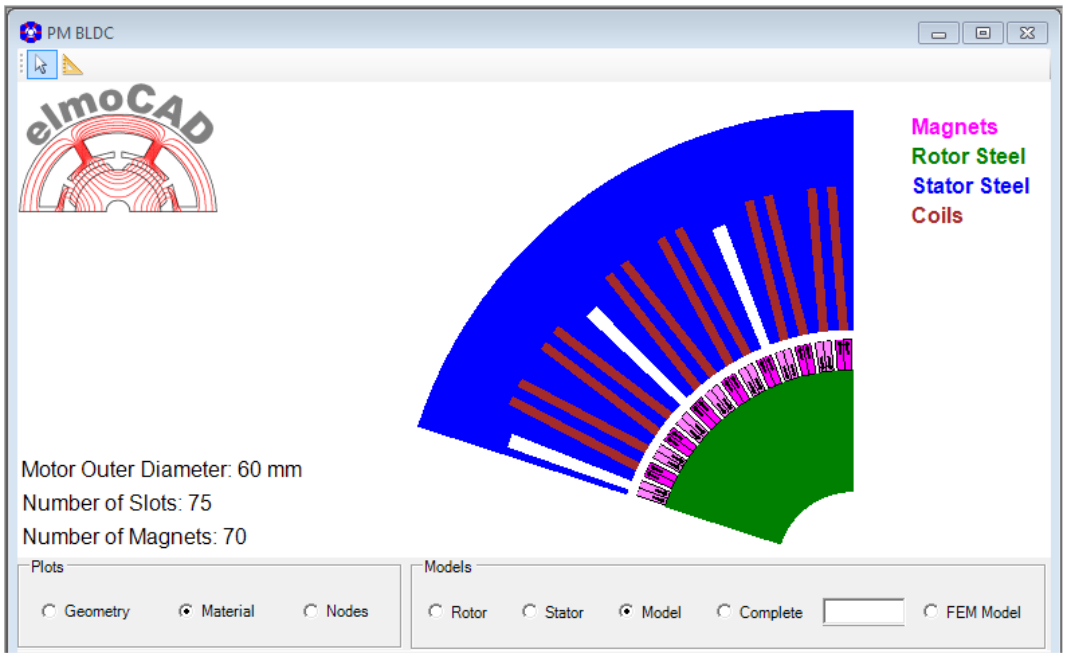
2.3.13 CS58_Segmented

With this can stator segments consisting of several geometrically different stator poles be modelled.

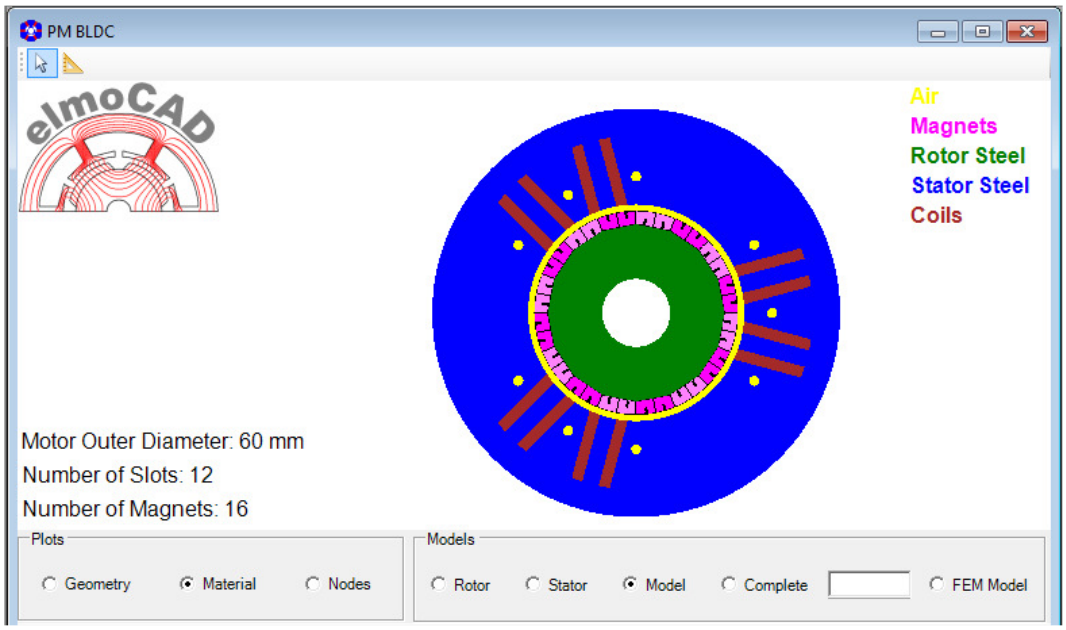
Example: 1 segment with each 5 slot (= 5 stator poles) whereby one slot without winding



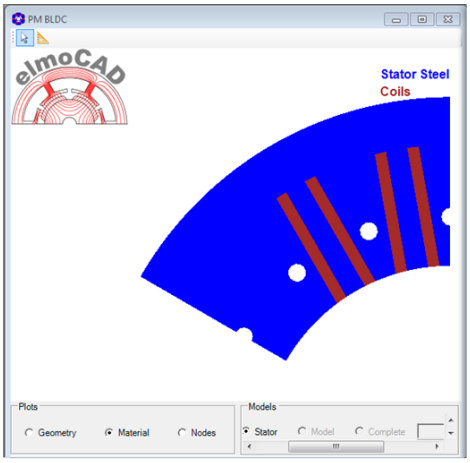
- 15 stator segments resulted from 75 stator poles



2.3.14 CS59_Segmented

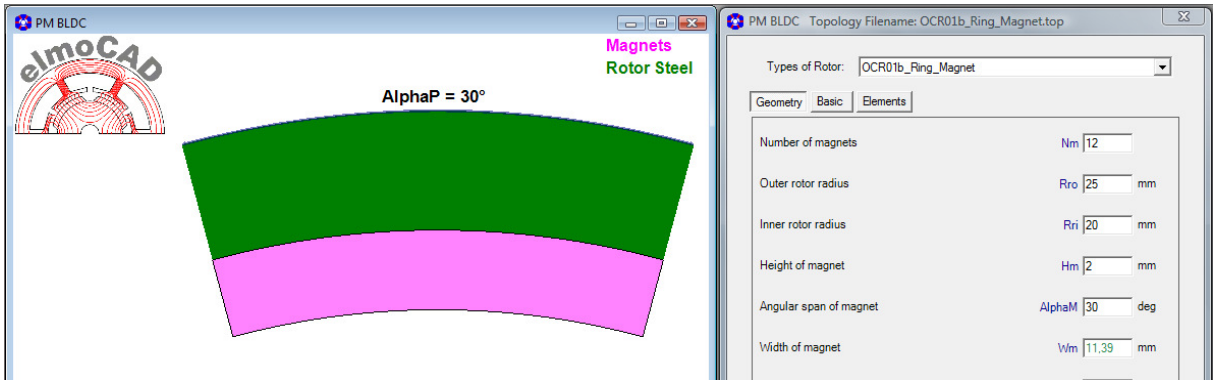


Same as 2.3.13 CS58_Segmented whereby the segment on the left side is completed without slots.

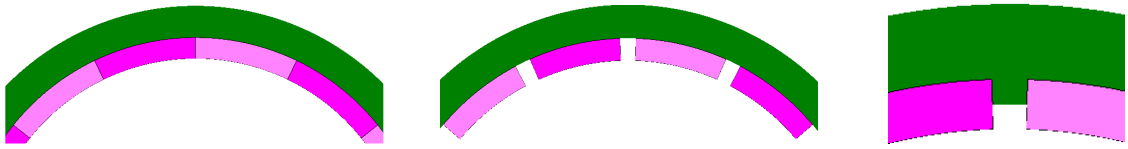


2.4 Outer Rotor

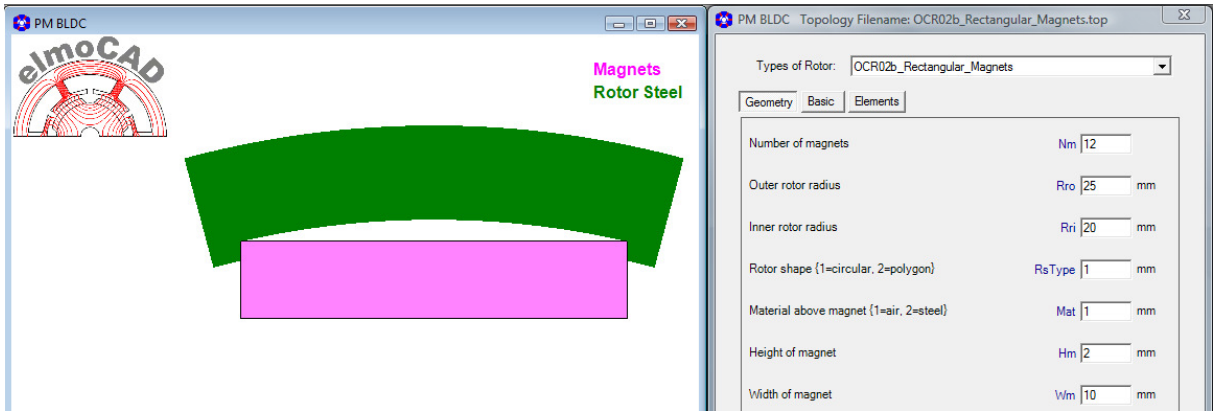
2.4.1 OCR01b_Ring_Magnet



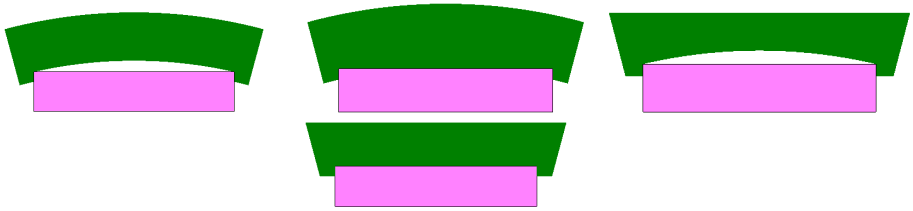
Possible designs:



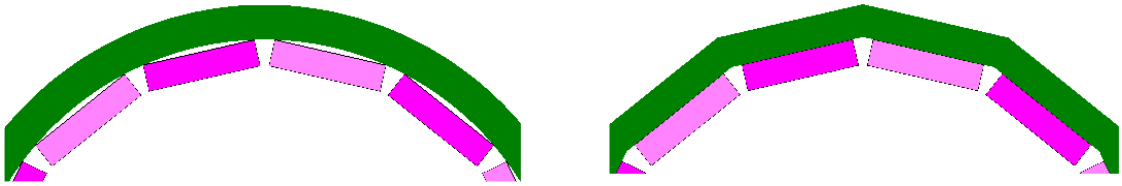
2.4.2 OCR02b_Rectangular_Magnets



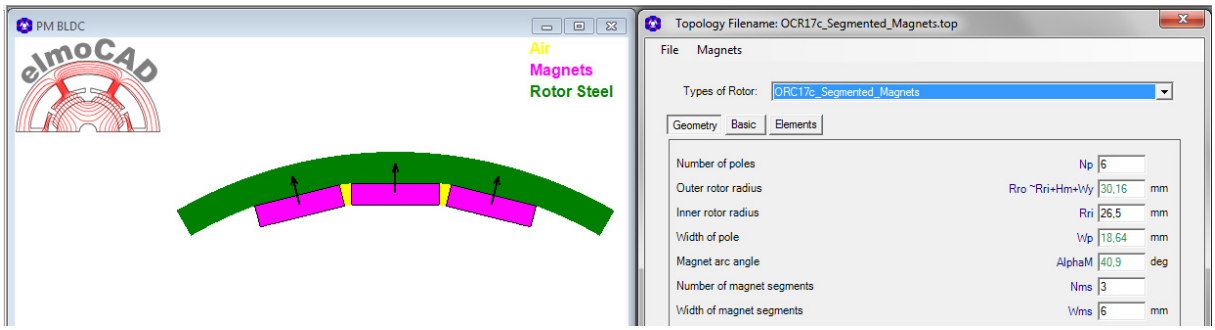
Possible designs for rotor surface and material above the magnet:



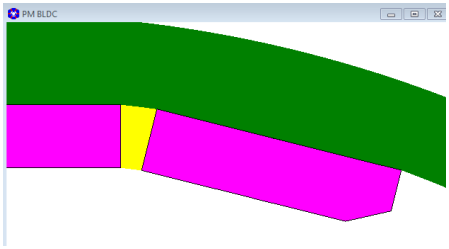
Arc, Air | Arc, Steel | Polygon, Air | Polygon, Steel



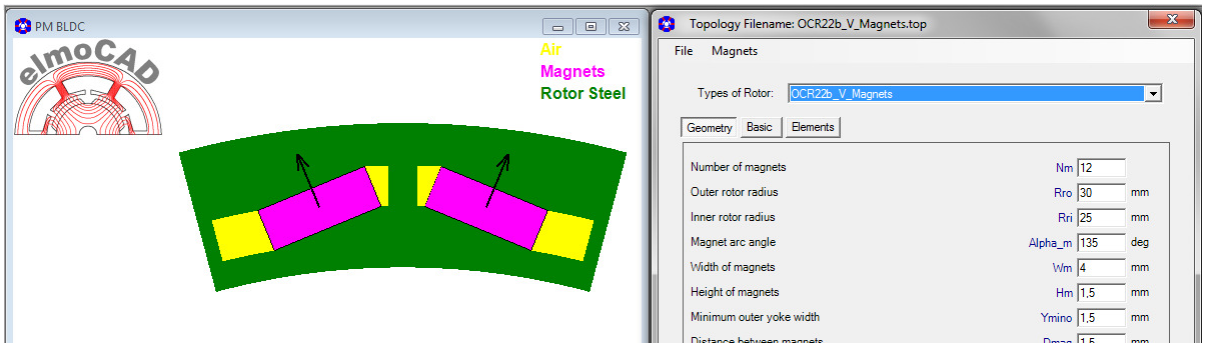
2.4.3 OCR17c_Segmented_Magnets



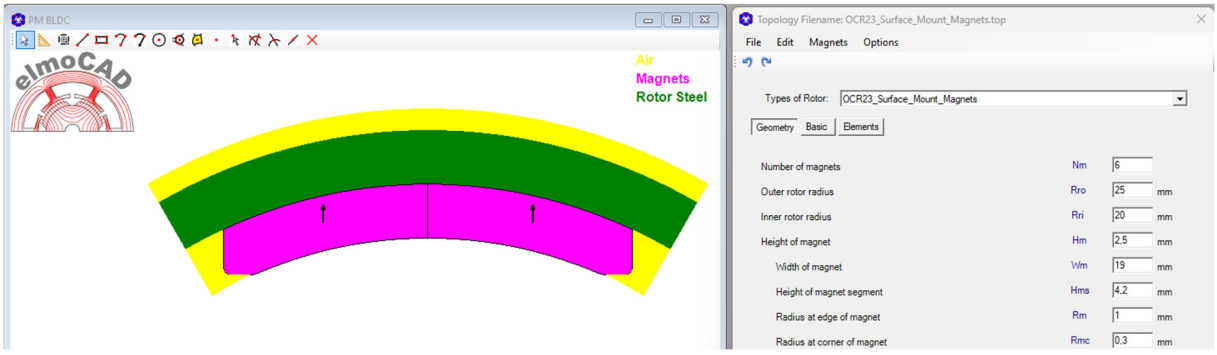
Possible design with or without beveled magnet sides



2.4.4 OCR22b_V_Magnets

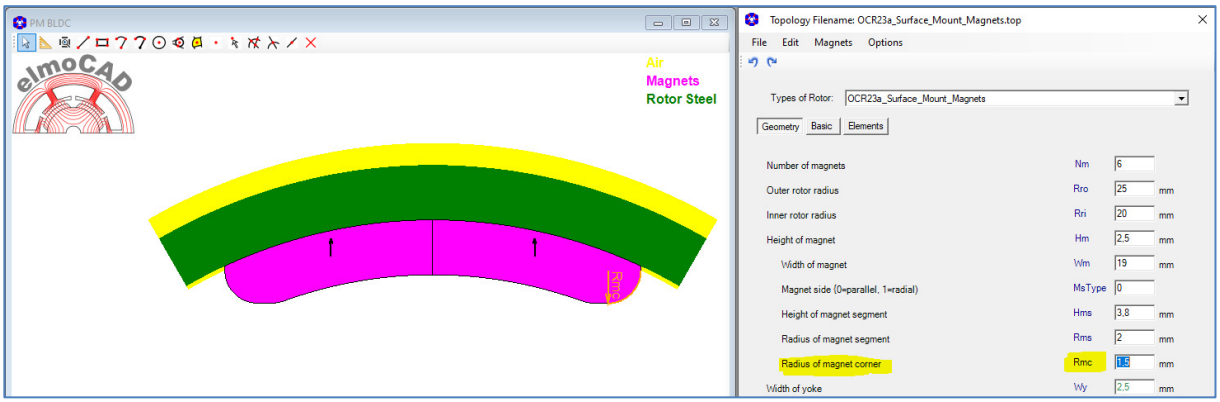


2.4.5 OCR23_Surface_Mount_Magnets

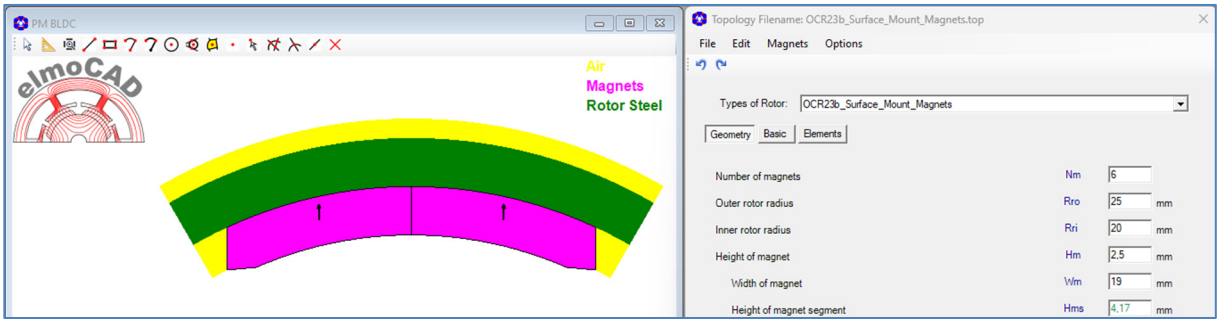


2.4.6 OCR23a_Surface_Mount_Magnets

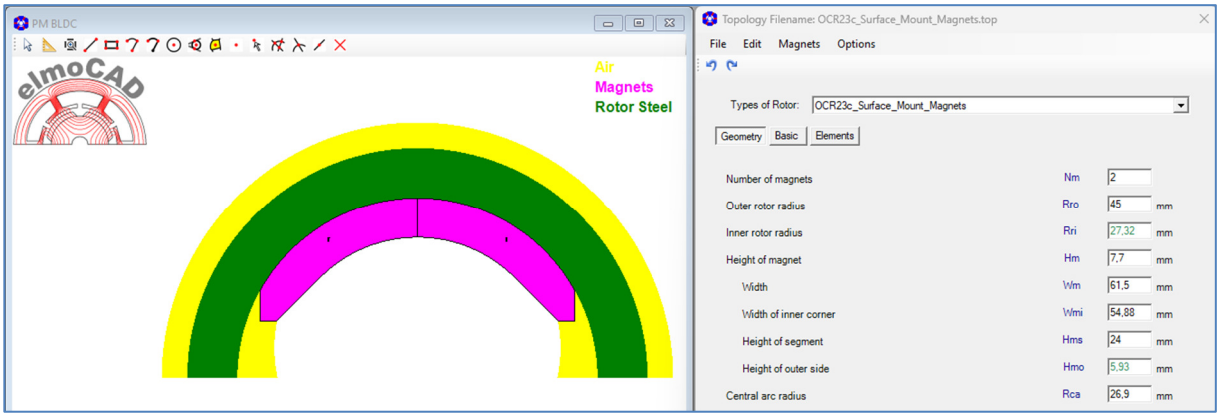
Diese Topologie wurde auf Basis der Topologie "OCR23_Surface_Mount_Magnets" mit dem neuen Parameter "Radius of Magnet Corner - Rmc" erstellt.



2.4.7 OCR23b_Surface_Mount_Magnets

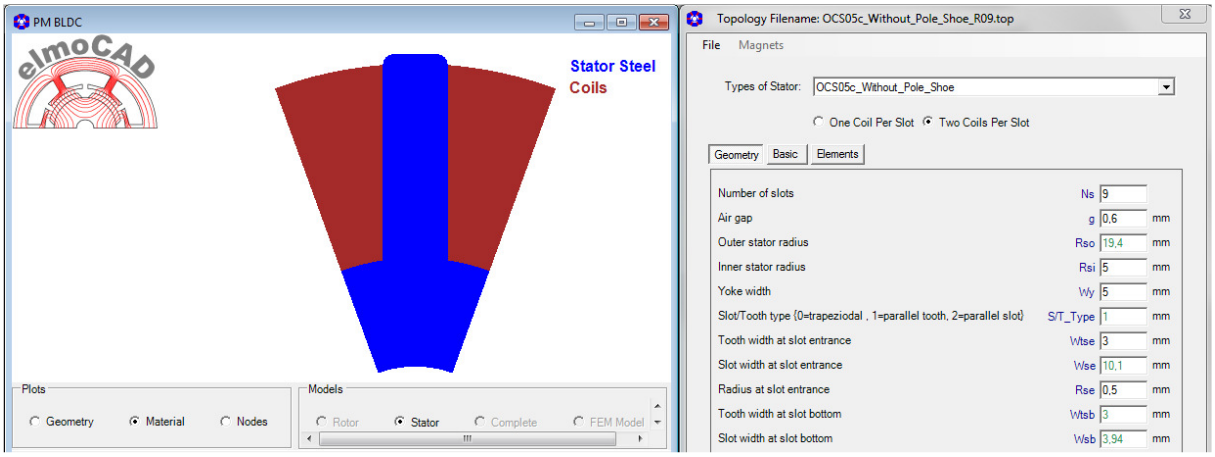


2.4.8 OCR23c_Surface_Mount_Magnets

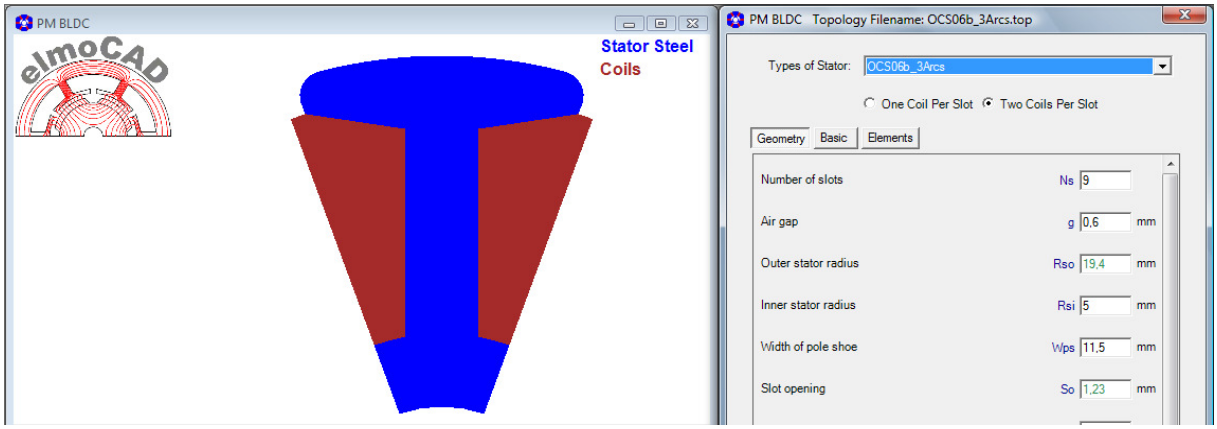


2.5 Außenläufer Stator

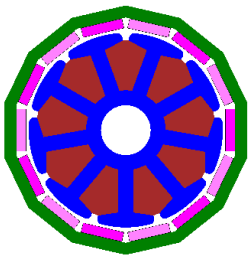
2.5.1 OCS05c_Without_Pole_Shoe

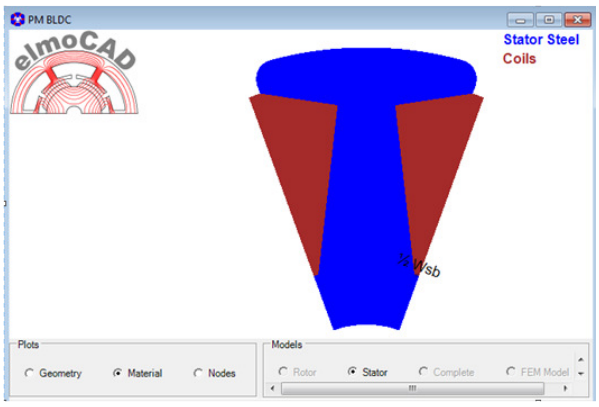


2.5.2 OCS06b_3Arcs and OCS06c_3Arcs



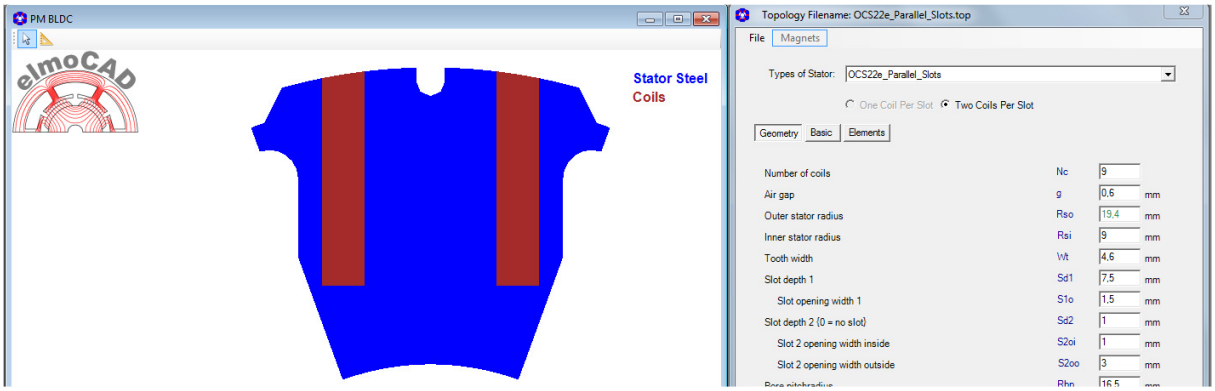
Example with representation of the motor geometry:

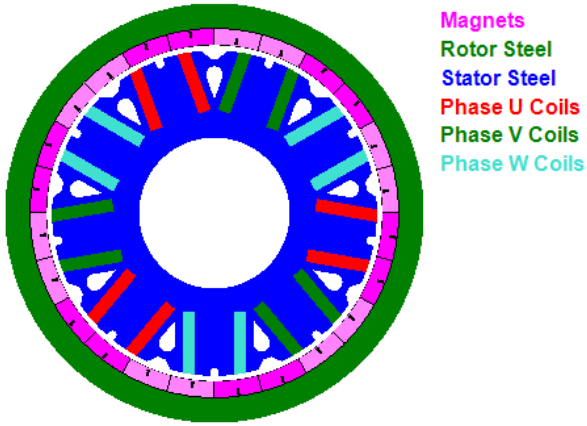




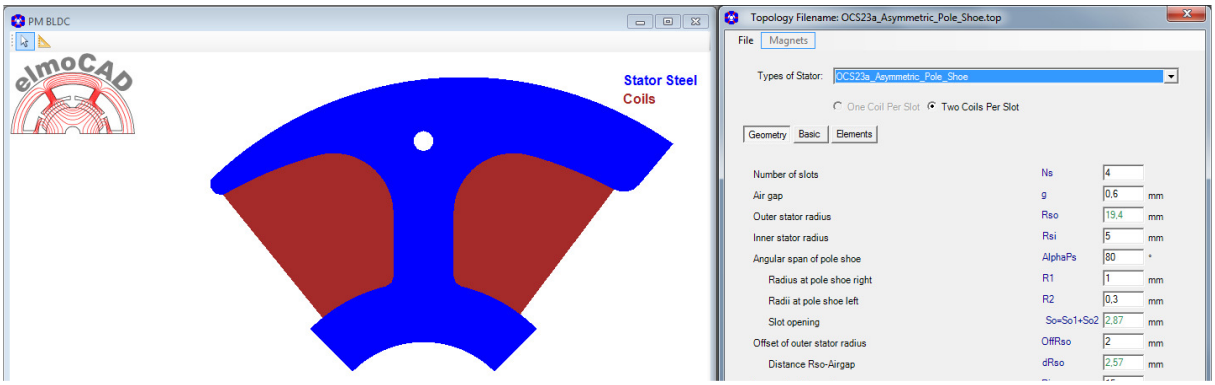
OCS06c_3Arcs same as OCS06b_3Arcs with the possibility to design the tooth with or without parallel tooth sides.

2.5.3 OCS22e_Parallel_Slots



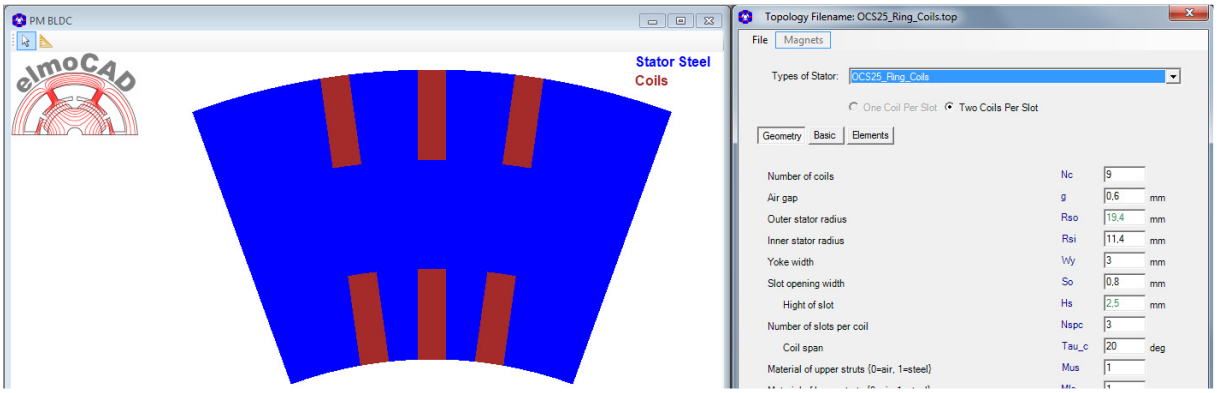


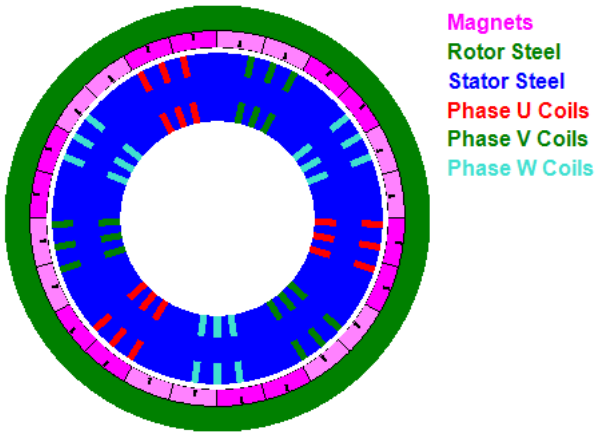
2.5.4 OCS23a_Asymmetric_Pole_Shoe



Zum Design von 1- bzw. 2-phasigen Motoren

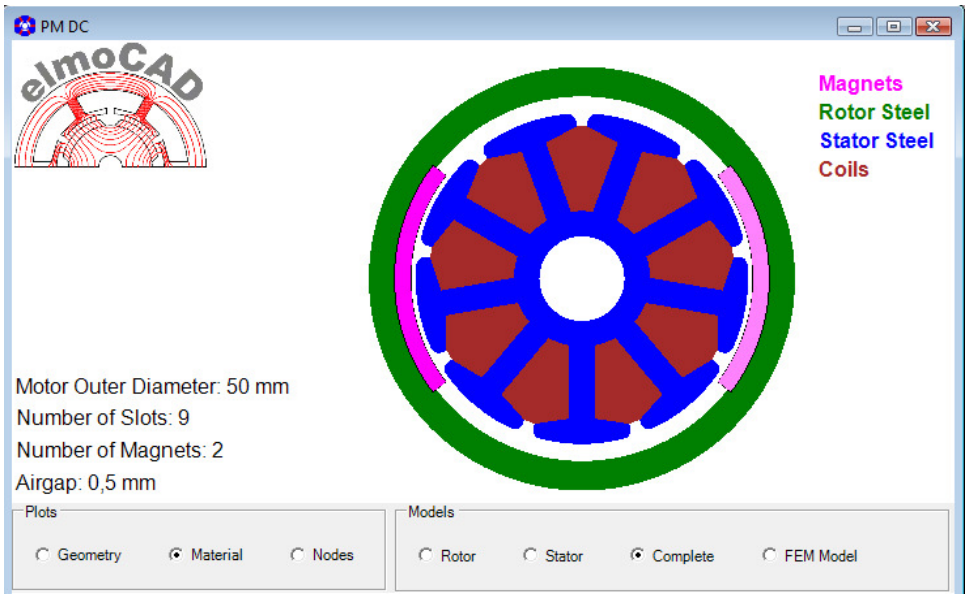
2.5.5 OCS25_Ring_Coils





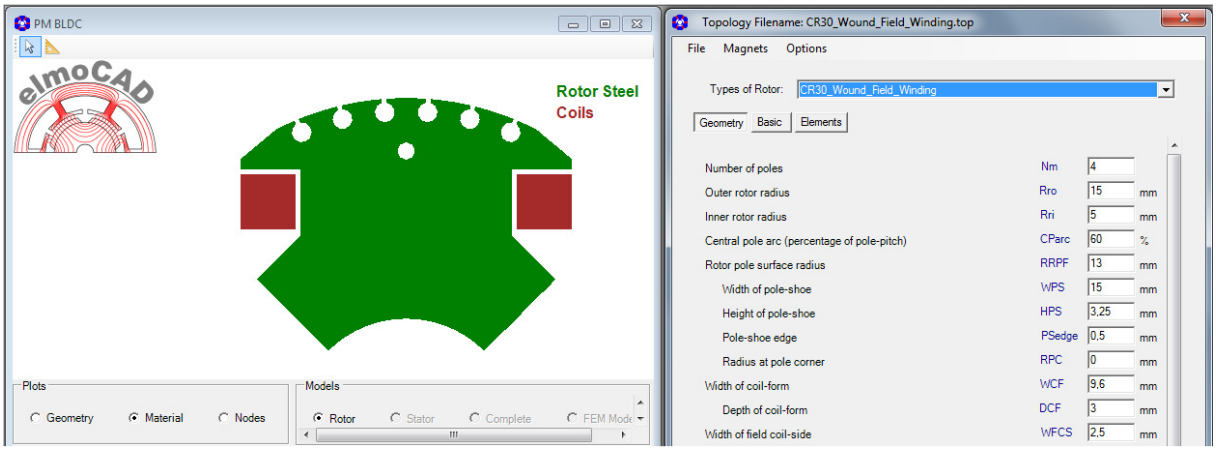
2.6 PM DC Motor

The topologies of brushed motors are the same as for outer rotor machines.

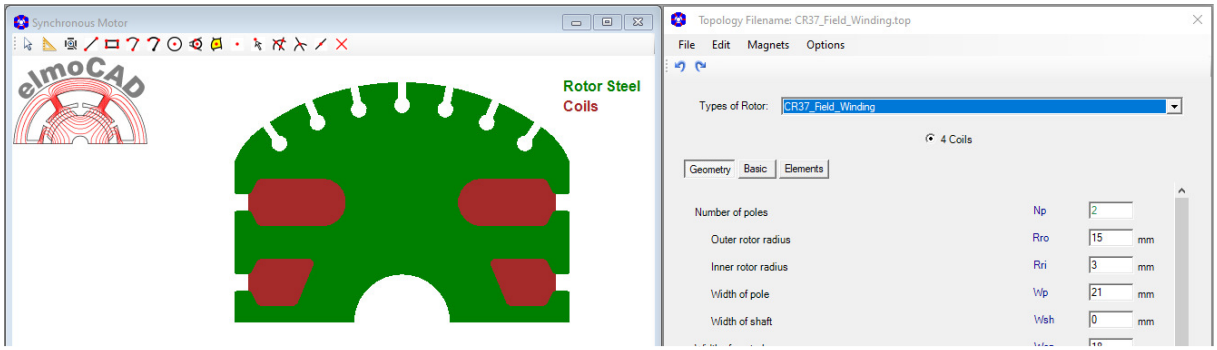


2.7 Synchronous Motor

2.7.1 CR30_Wound_Field_Winding



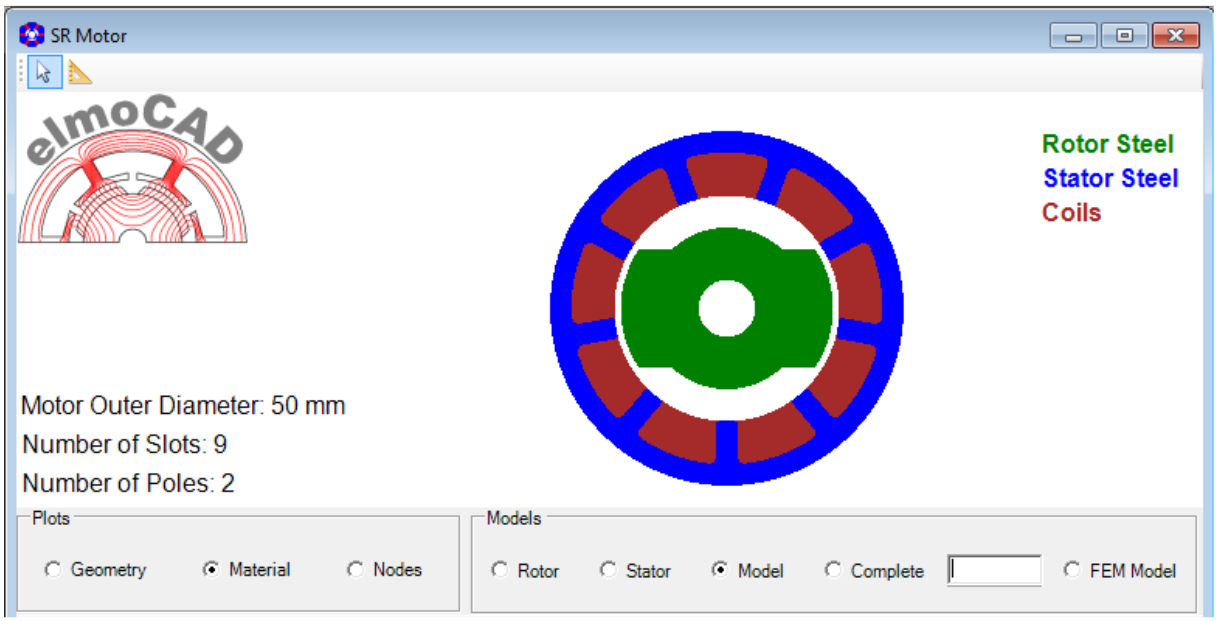
2.7.2 CR37_Field_Winding

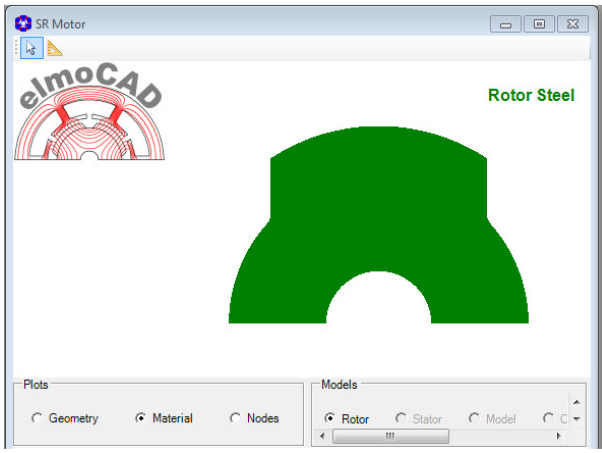


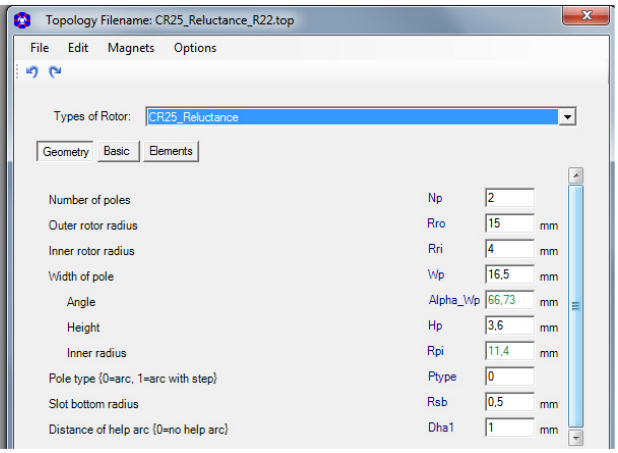
2.8 SR Motor (Switched Reluctance Motor)

2.8.1 CR25_Reluctance

For the design of 2-pole reluctance machines.



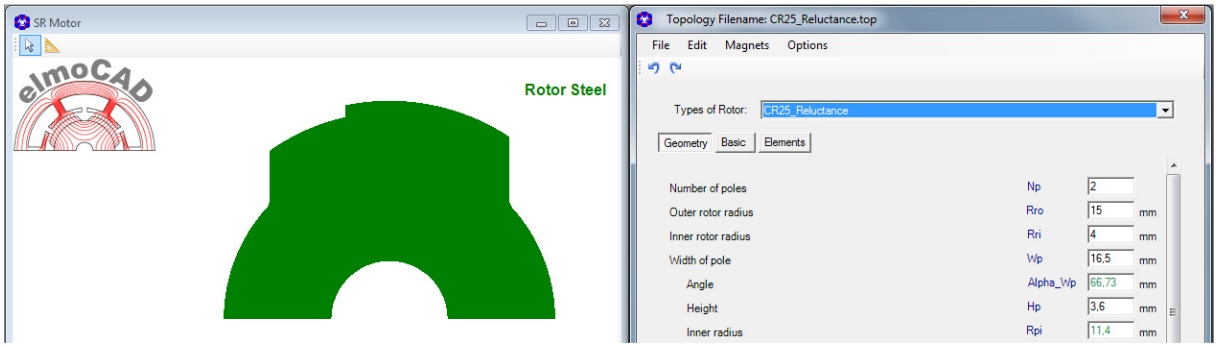




2.8.2 CR32_Reluctance_Stepped

For the design of 2-pole reluctance machines whereby the rotor is stepped at the outer rotor radius to define the start direction.

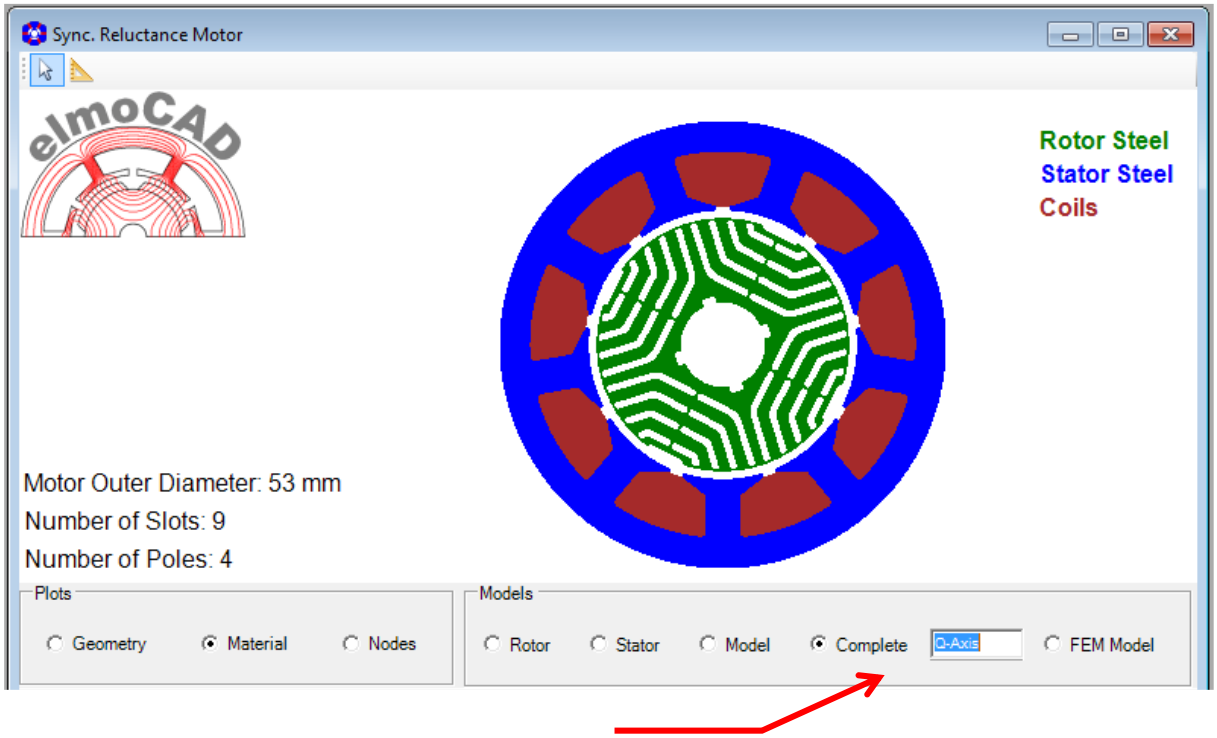
In view *"Complete"* can the rotor be rotated into the alligned , unalligned or any other position.



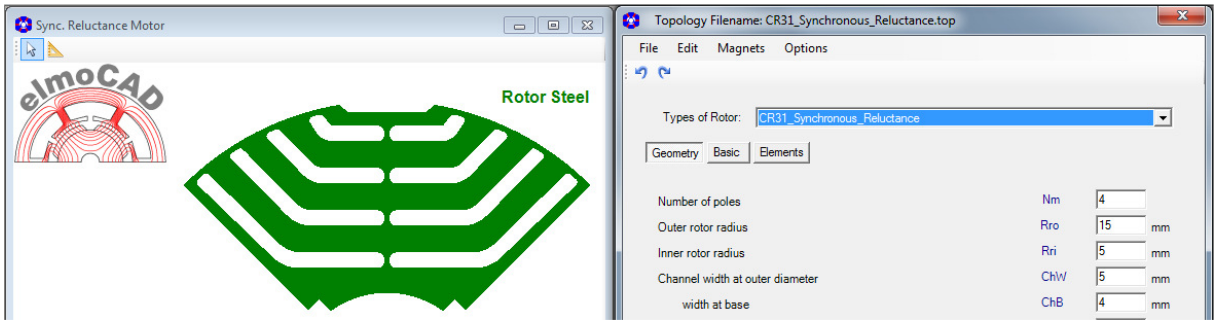
2.9 Synchonous Reluctance Motor

2.9.1 CR31_Synchronous Reluctance

For design of 4 pole synchronous reluctance machines with 1, 2 3 or 4 barriers.

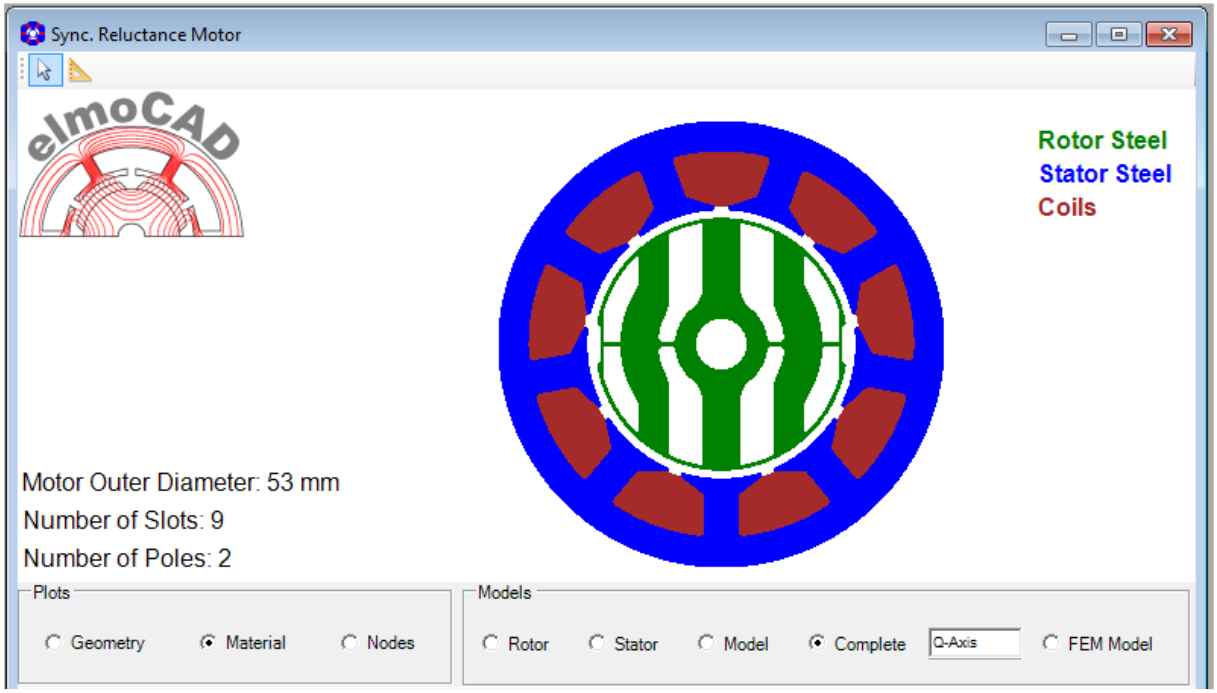


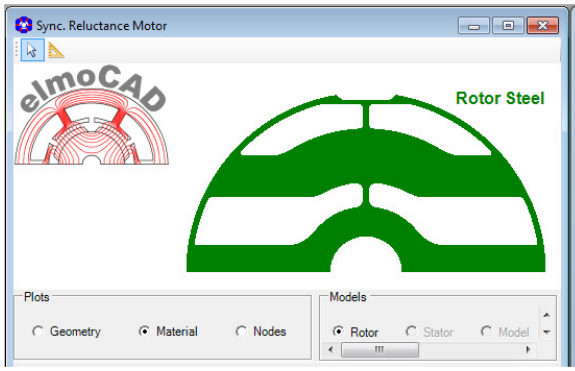
In view “Complete” can the rotor be rotated into the d-axis, q-axis or any other position.

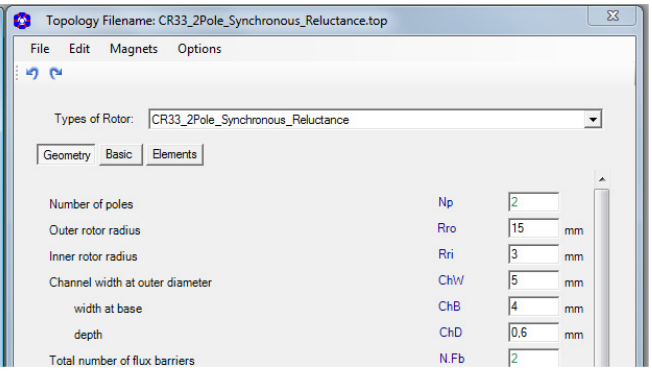


2.9.2 CR33_2Pole_Synchronous Reluctance

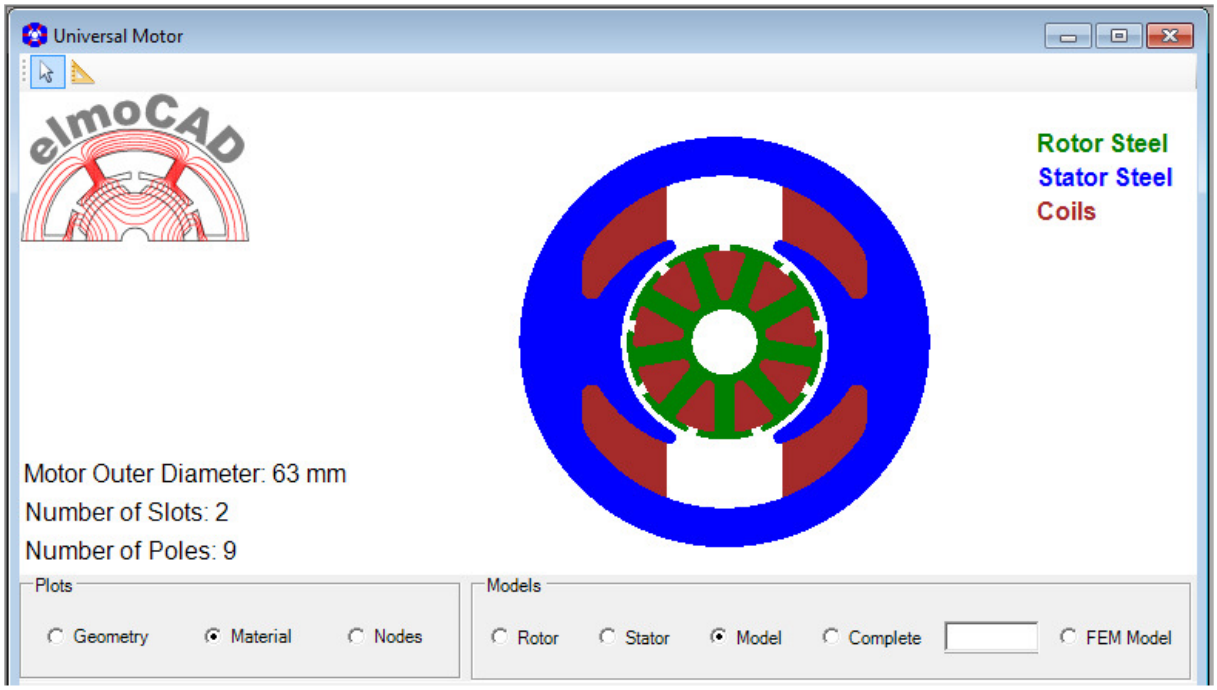
For design of 2 pole synchronous reluctance machines with 2 barriers.



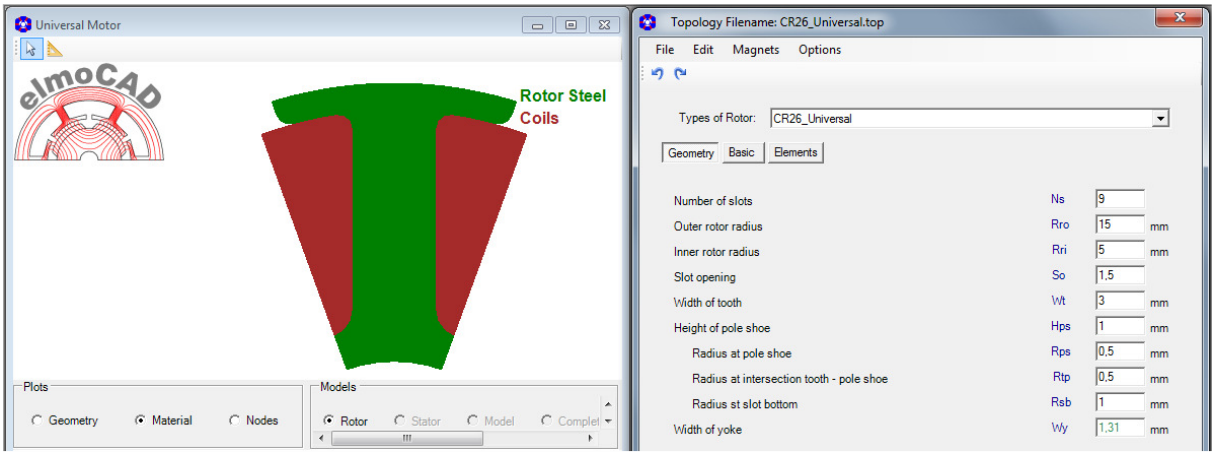




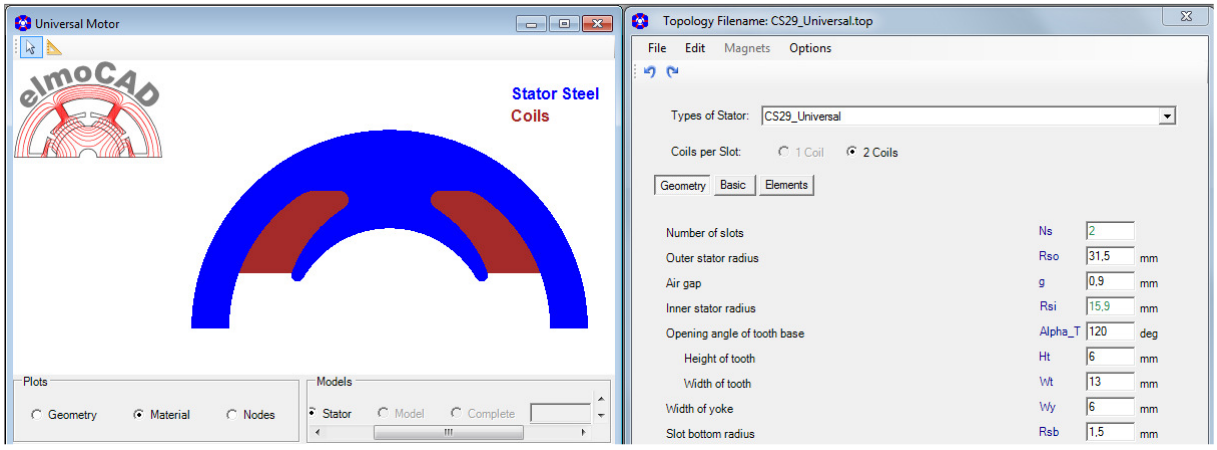
2.10 Universal Motor



2.10.1 CR26_Universal



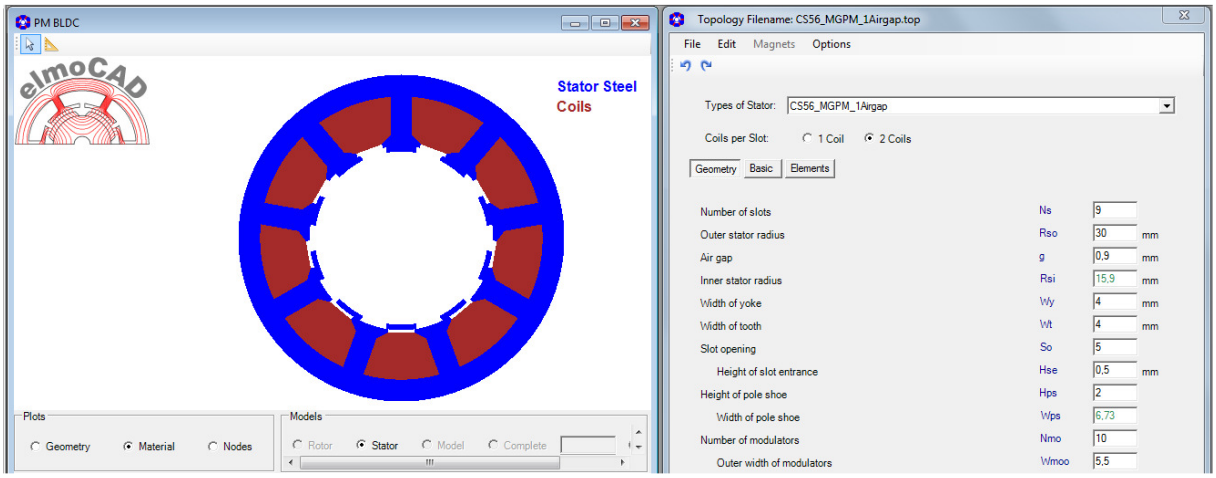
2.10.2 CS29_Universal



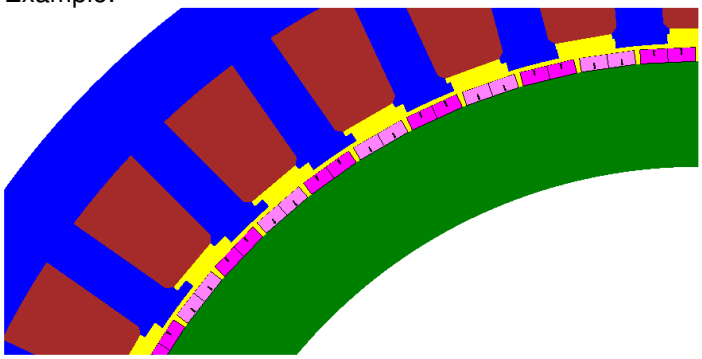
2.11 PM-Machines with Magnetic Gear

2.11.1 CS56_MGPM_1Airgap

For design of Magnetic Geared Permanent Magnet Machines with one airgap. Reference: “Comparison and Analysis of Magnetic-Geared Permanent Magnet Electrical Machine at No-Load” Xiping Liu, Dong Chen, Liang Yi, Chao Zhang, Min Wang (DOI 10.2478/aee-2014-0047)

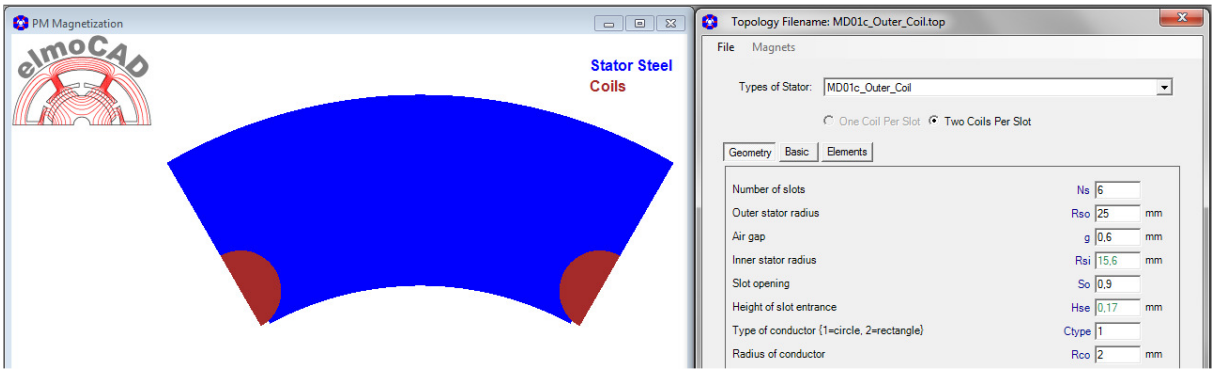


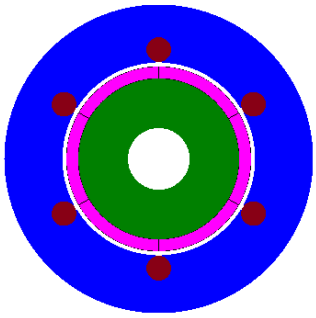
Example:



2.12 Magnetization of Inner Rotors

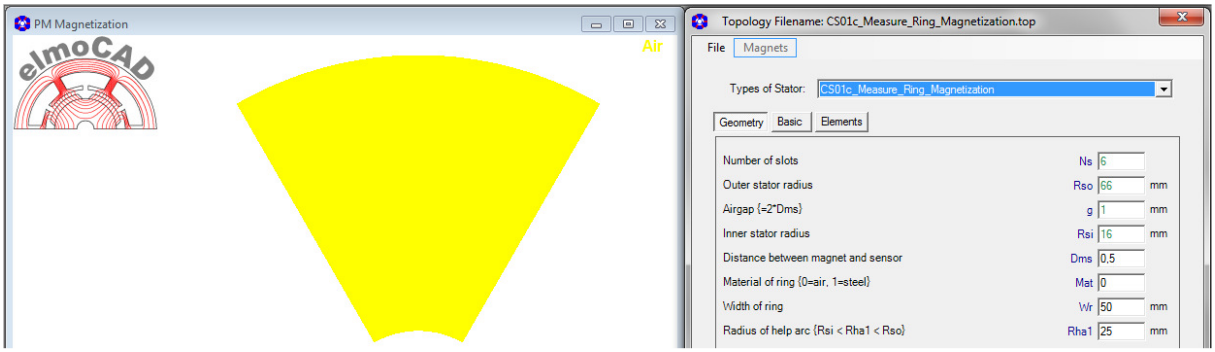
2.12.1 MD01d_Outer_Coil (Magnetising Coil)

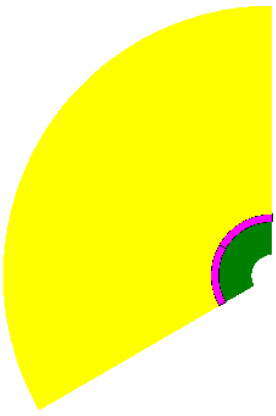




Presentation of a magnetizing device for ring magnets with 6 poles

2.12.2 CS01c_Measure_Ring_Magnetization

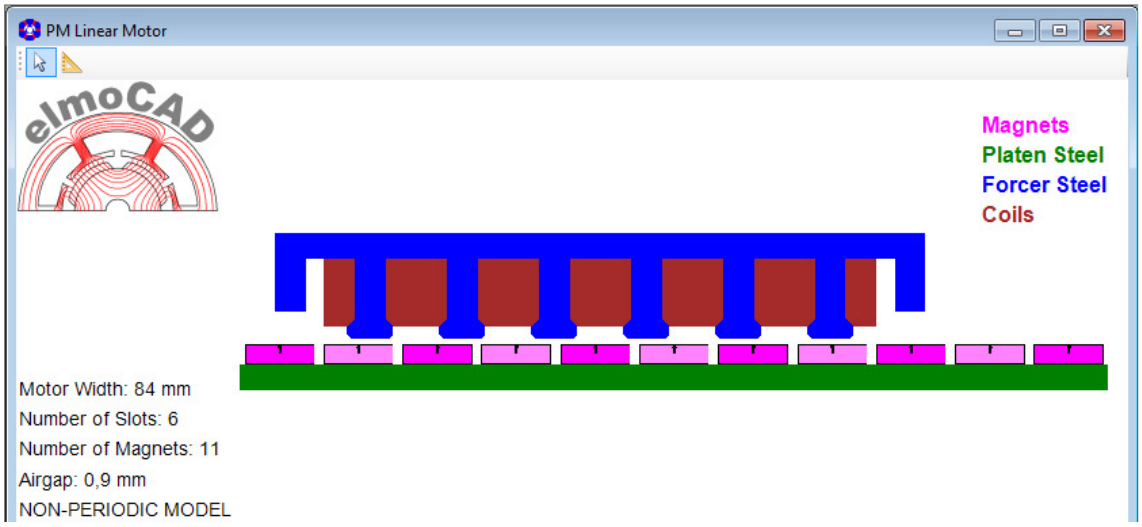




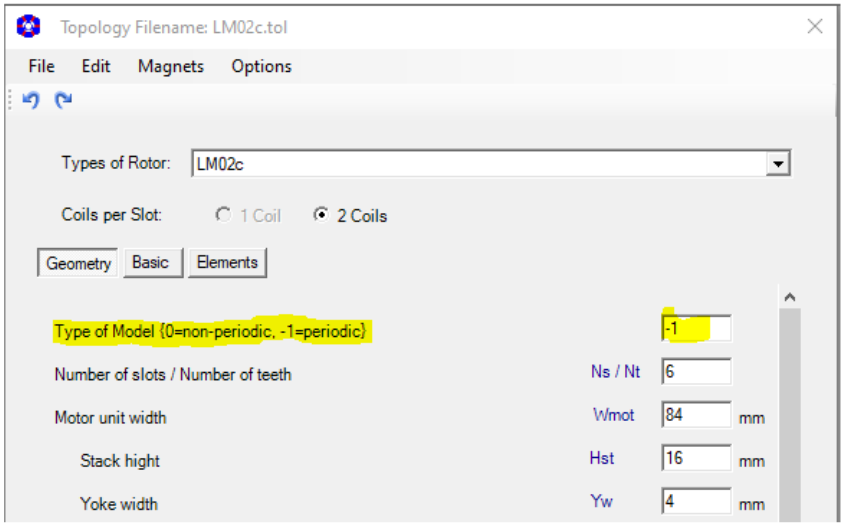
A “stator” made out of air is modelled to calculate the flux density in the airgap between rotor and stator.

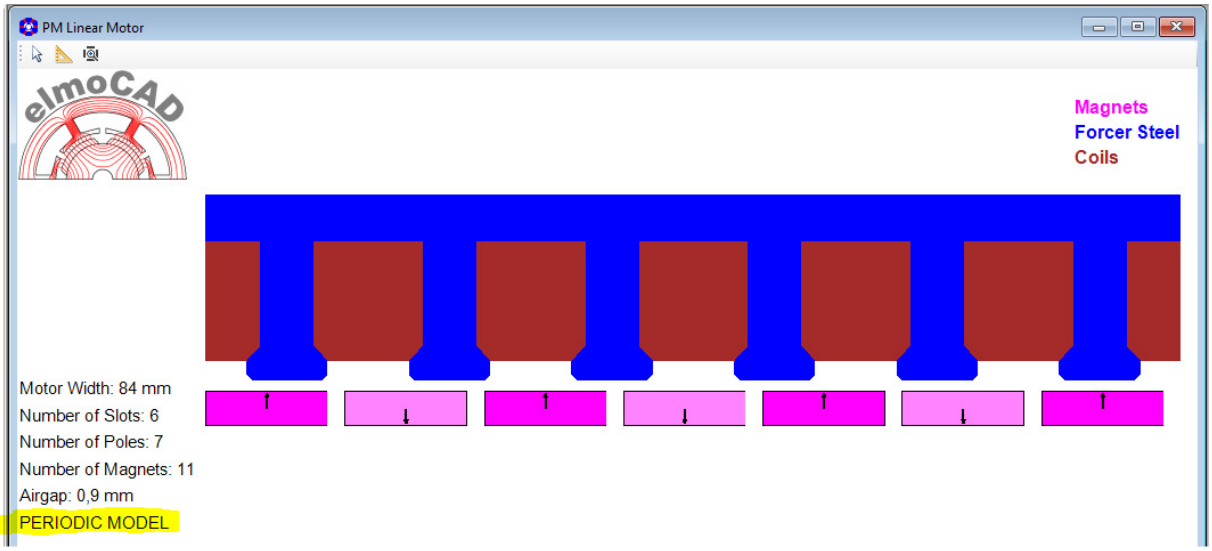
3.1 Linearmotor

3.1.1 LM02c



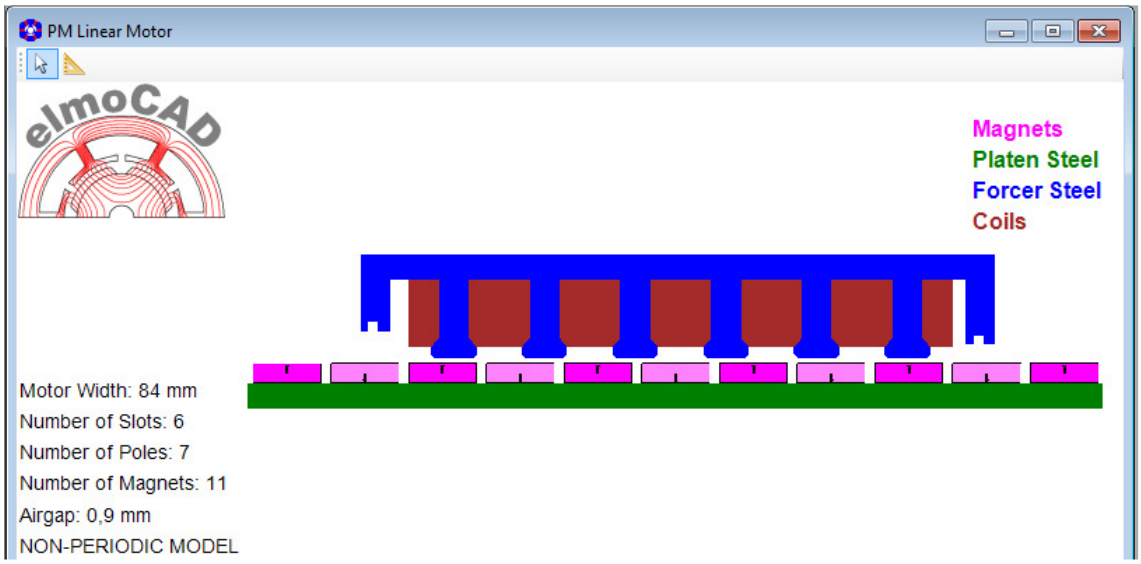
By parameter *„Type of Model (0=non-periodic, -1=periodic)"* can user select between non-periodic and periodic geometry. This function is available in different linear motor topologies. Reason is that losses only can be calculated of periodic linear motor models.



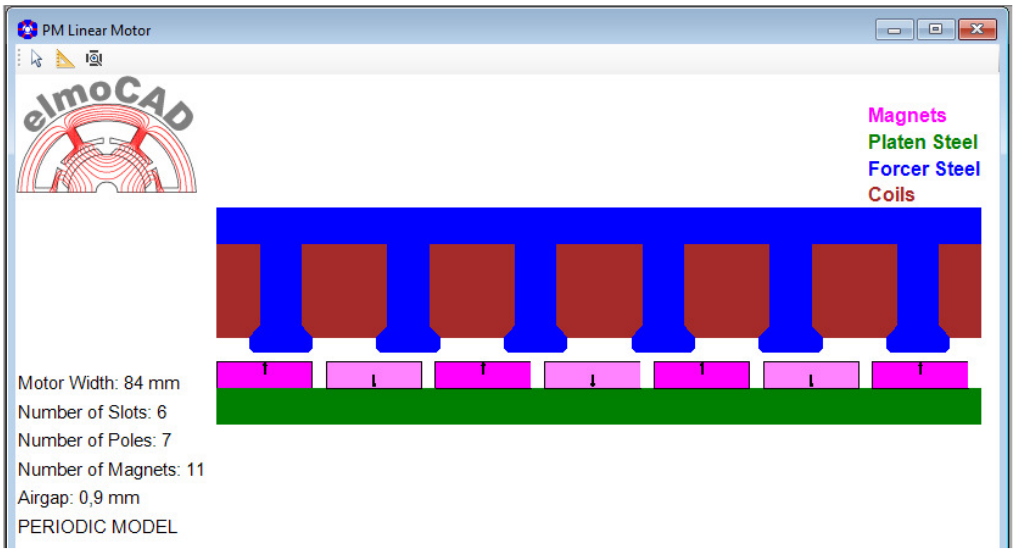


3.1.2 LM021c

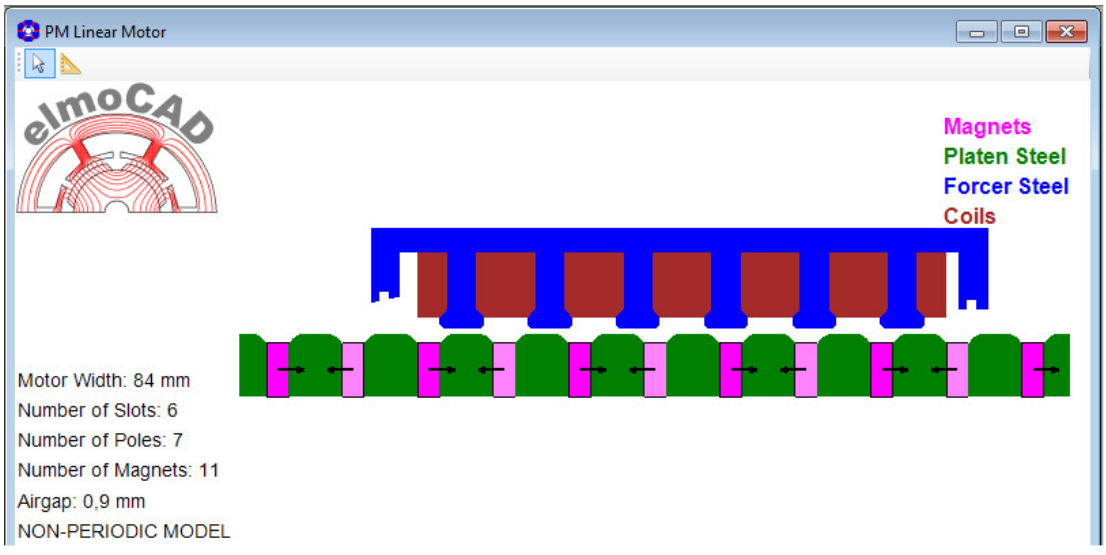
Same as LM02c with enhancements



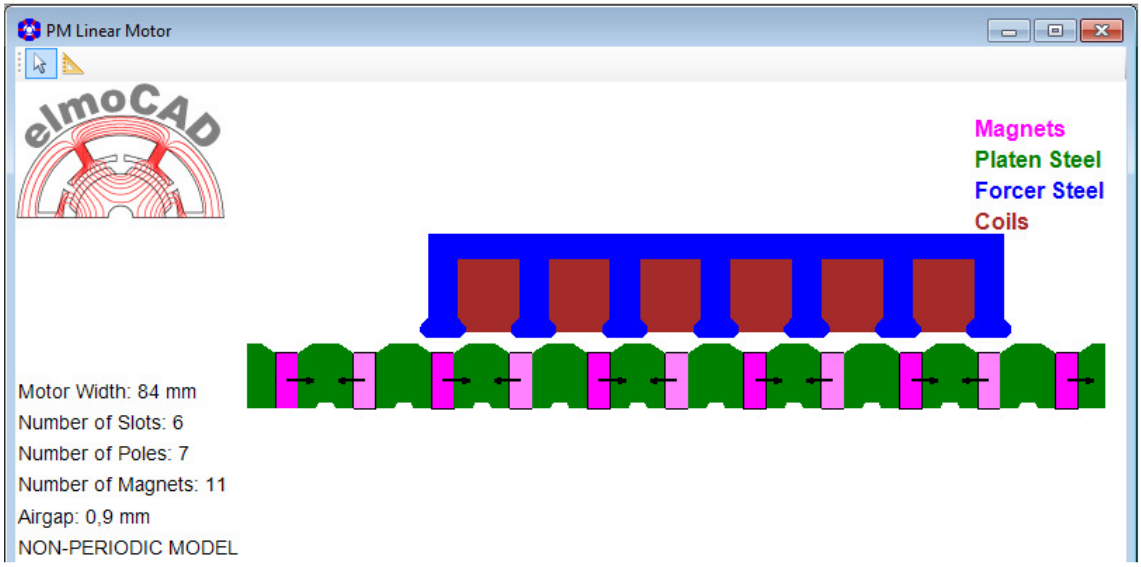
LM021c as periodic model for loss calculation



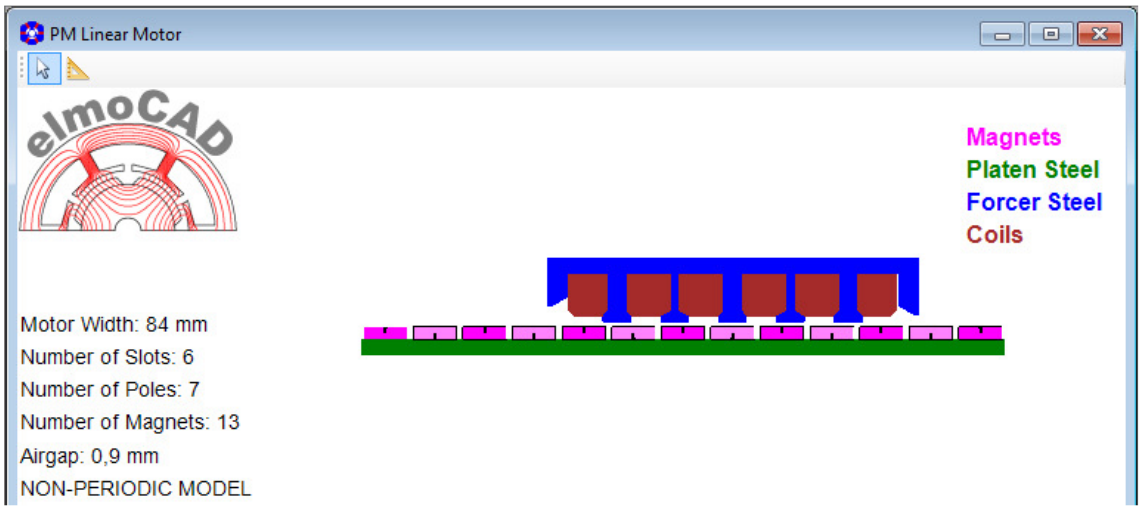
3.1.3 LM03c



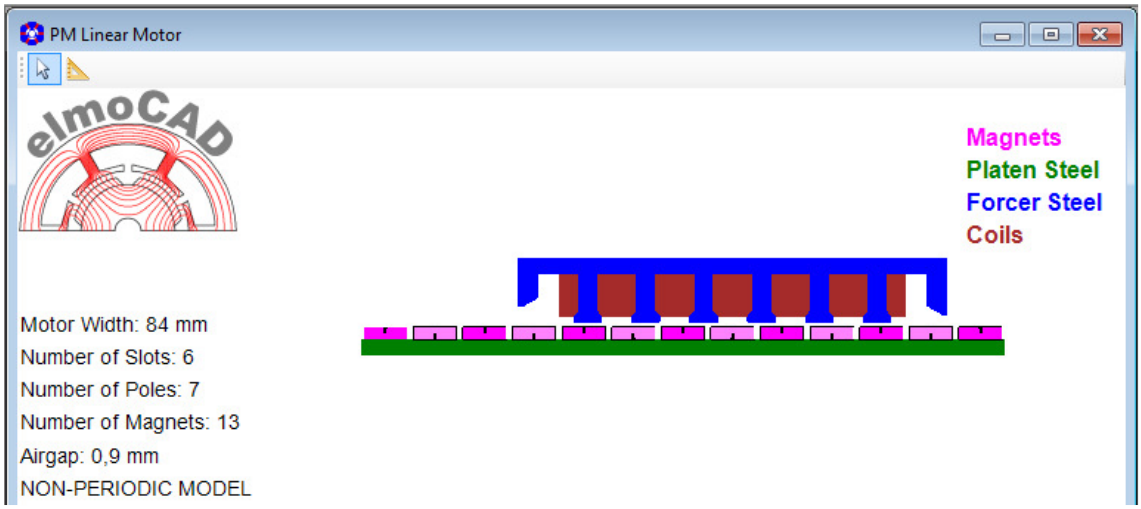
3.1.4 LM04



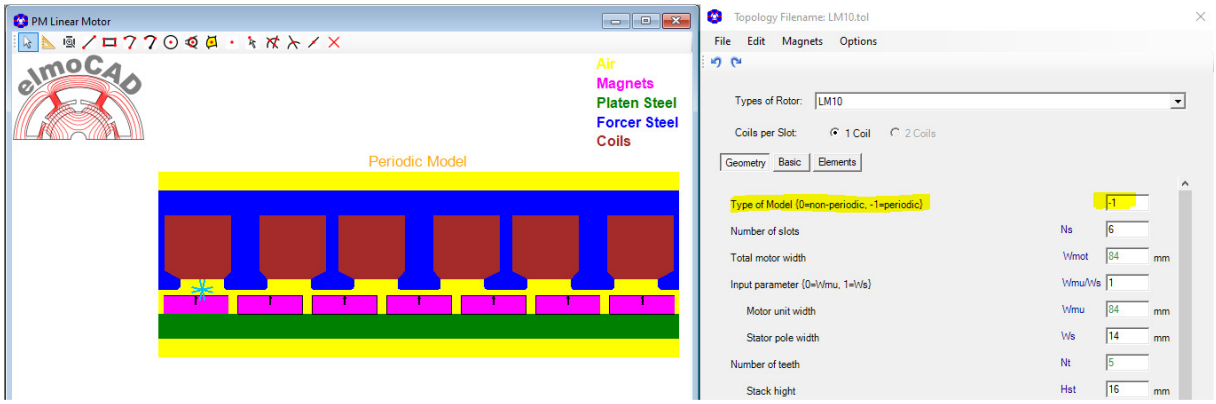
3.1.5 LM10



Design with single layer winding and modification of the teeth between the different phases.

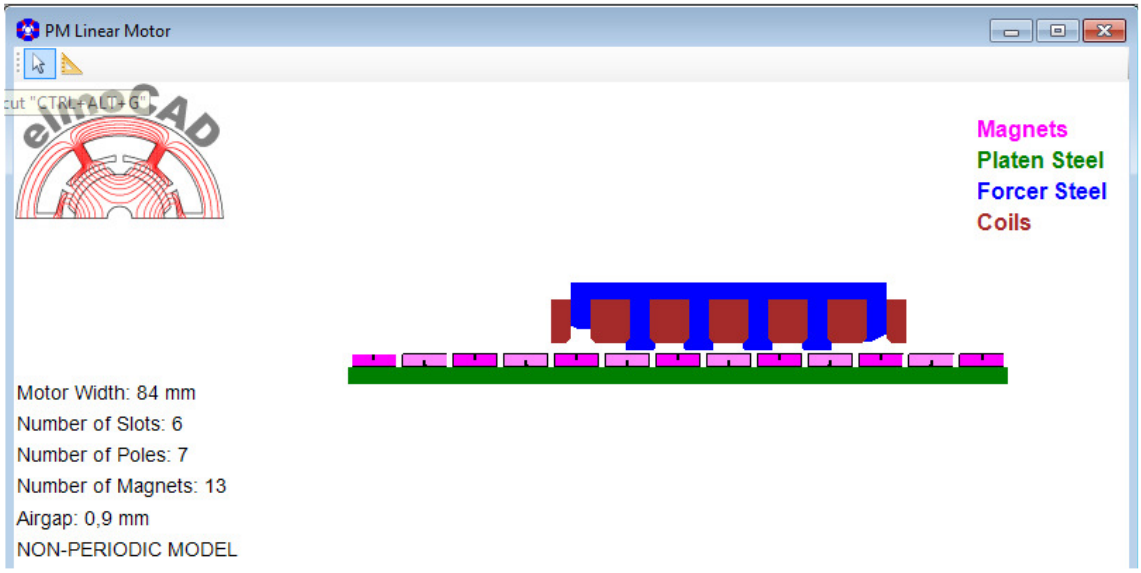


Design with double layer winding.

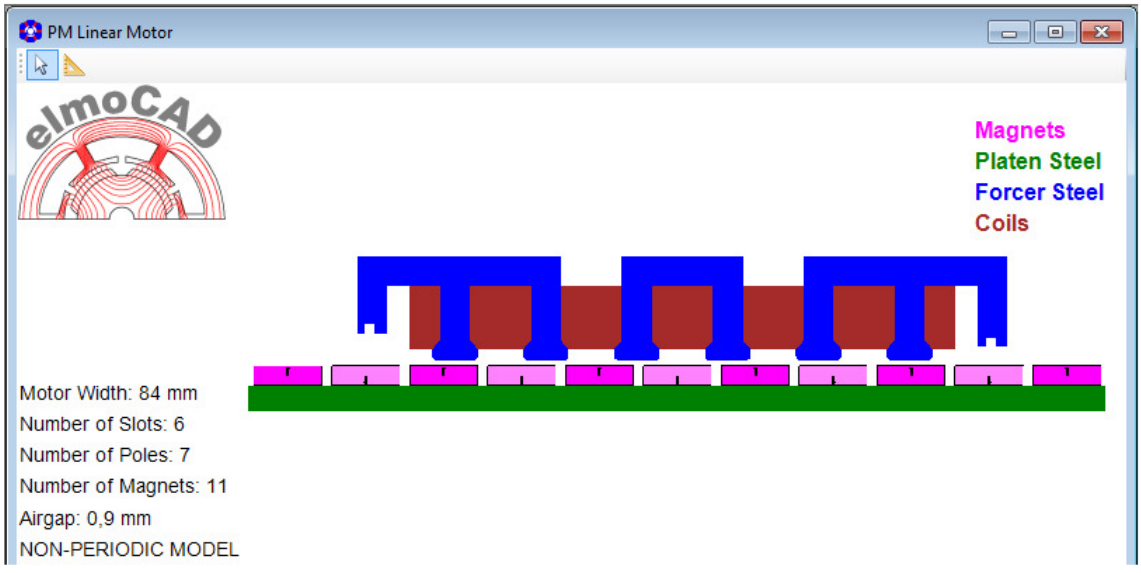


Design with different width of the teeth presented as *"periodic"* geometry. By this is it possible to calculate electric steel and magnet losses

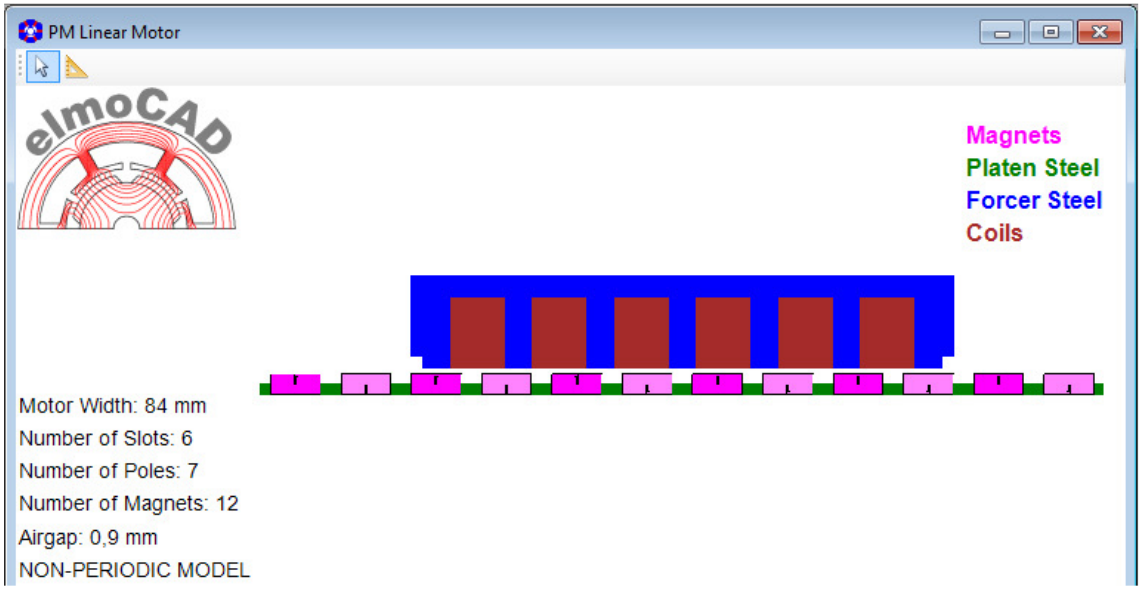
3.1.6 LM11



3.1.7 LM422

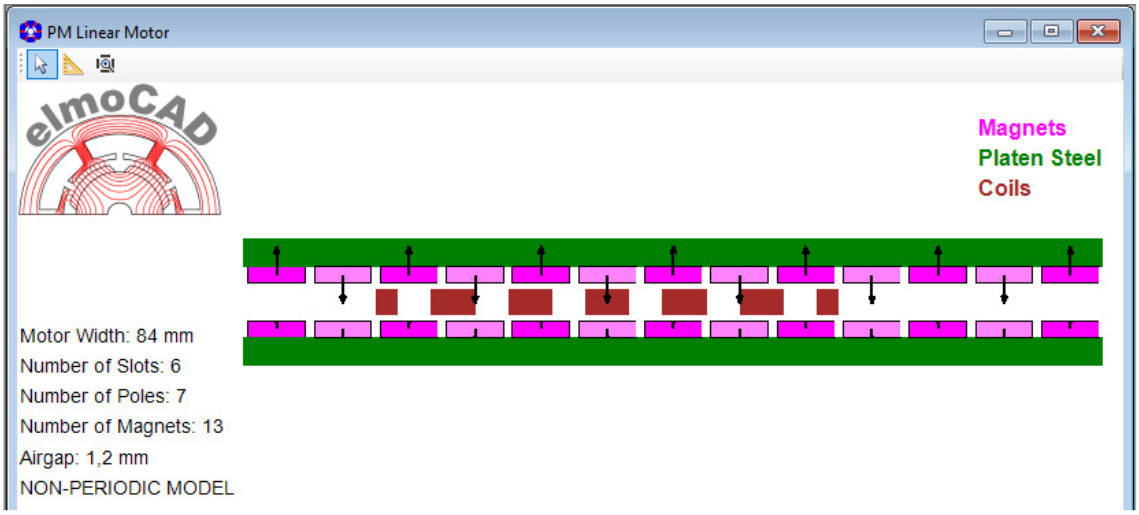


3.1.8 LM544



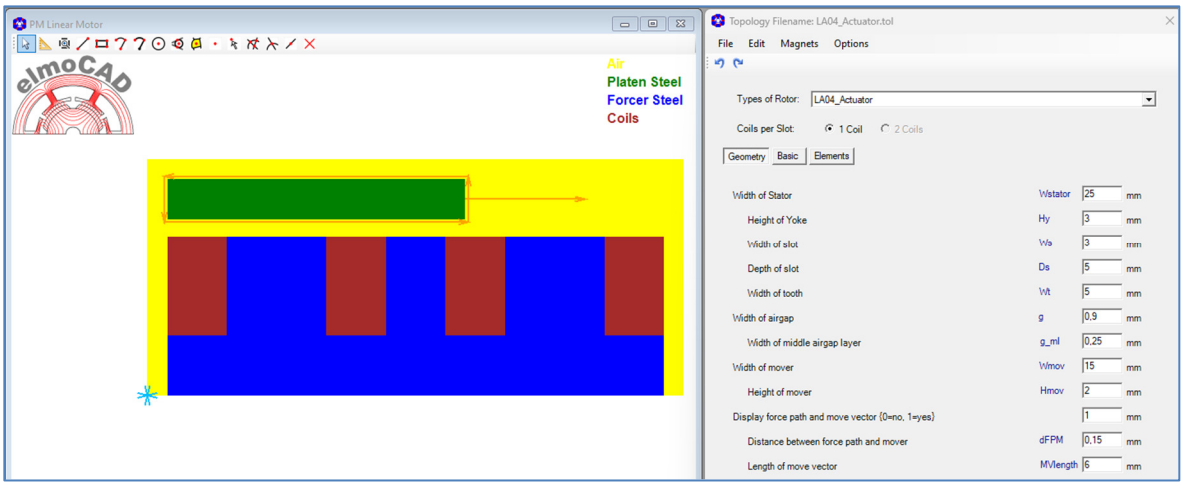
3.1.9 LM60_Double_Airgap

With double layer airgap winding



4 Actuator

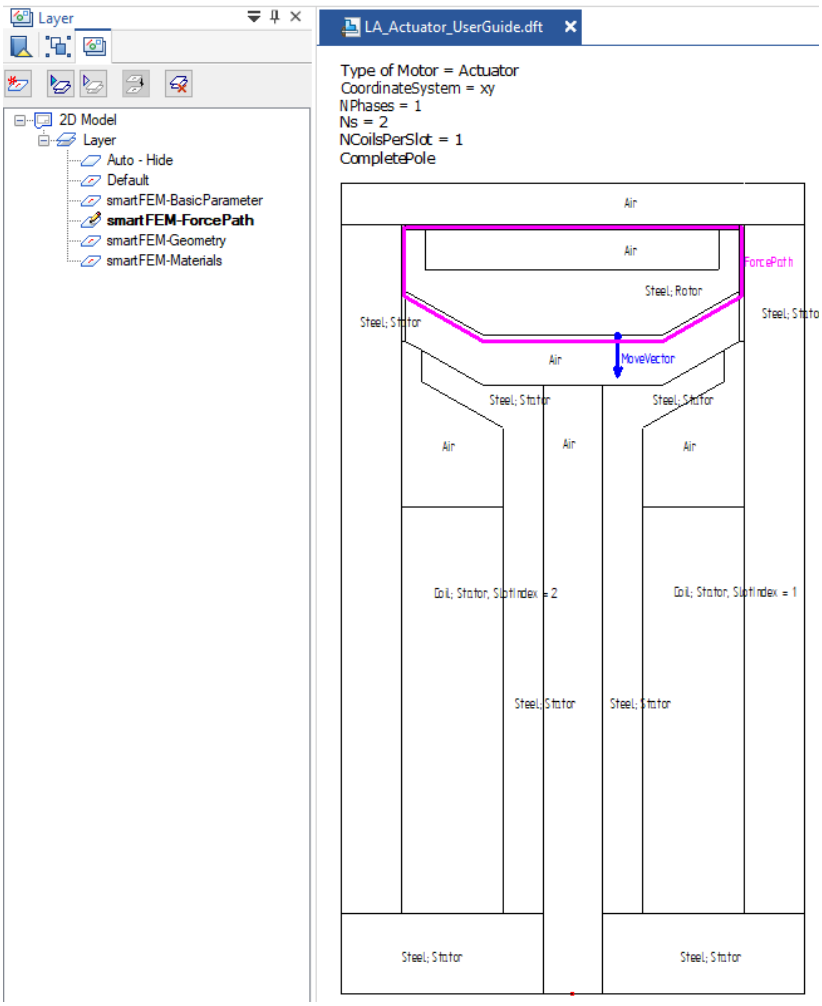
4.1 LA04



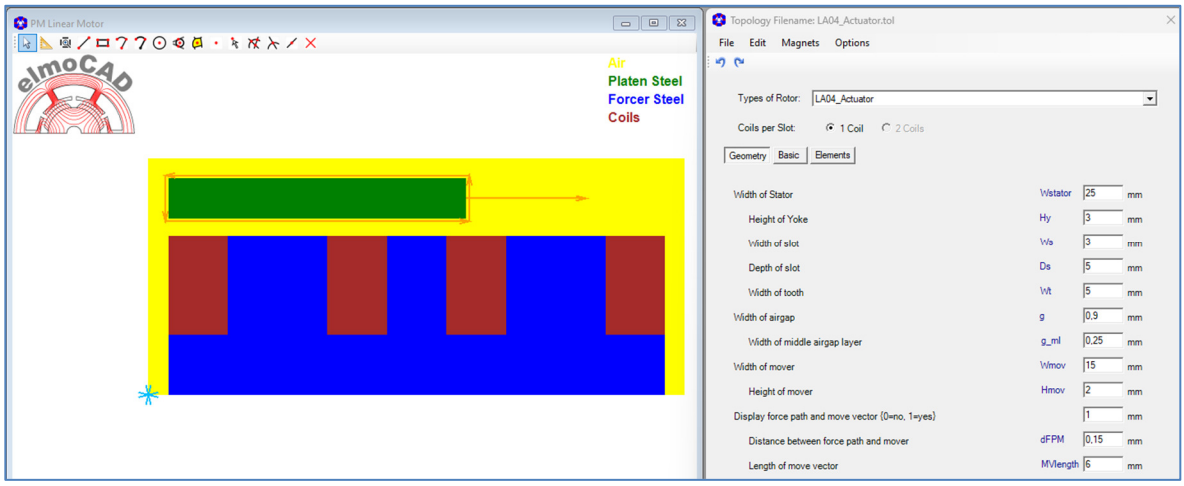
4.2 LA_CADdata

Actuators have a very client specific design. By the topology “LA_CADdata” can geometrias which are created with a CAD program be imported into smartFEM as DXF drawing and simulated. For details see ***“UserGuide“***.

Example:



Presentation in smartFEM after DXF import



smartFEM rotates the imported geomtry in such a way that the movement direction is aligned with the x-axis in order to calculate the horizontal and vertical forces.

5 Personal Notice