

# smartFEM

### **Analysis and Design of Electrical Drives**

## **Rotor and Stator Topologies**

smartFEM 2.013.00 - 01.03.2022

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| Pers | Personal Notice |                                     |    |  |  |  |  |  |

#### 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 preprogrammed 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.

| Ç | 👌 sm | artFEM   |         |         |        |  |
|---|------|----------|---------|---------|--------|--|
| Γ | File | View     | Tools   | Windows | s Help |  |
|   |      | New      |         | Strg+N  | 3      |  |
| Ì | 2    | Open     |         |         | •      | With Rotor Topology Saved in mot-File            |
|   |      | Save     |         | Strg+S  |        | With Stator Topology Saved in mot-File           |
| I |      | Save As  |         |         |        | With Rotor and Stator Topology Saved in mot-File |
|   |      | DXF Expo | ort     |         | · .    |  |
|   |      | FEMAG    |         |         | •      |  |
|   |      | Generate | Project | Report  |        |  |
|   |      | Exit     |         | Alt+F4  |        |  |
|   |      |          |         |         | _      |  |

#### 1.3 DFX Export

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

| File | View Tools Windows Help   |        |                          |                                 |  |
|------|---|--------|--------------------------|---------------------------------|--|
|      |   |        | - 23                     |                                 |  |
|      | 1ew   | Strg+N |                          |                                 |  |
| 💕 (  | Open  |        | 2 H                      |                                 |  |
| 🚽 s  | ave   | Strg+S | - 11                     |                                 |  |
| s    | ave As  |        | - 11                     |                                 |  |
| 0    | IXF Export  |        | •                        | Rotor                           |  |
| F    | EMAG  |        | •                        | Stator                          |  |
| 0    | Senerate Project Report   |        |                          | Periodic Model                  |  |
| L    | k\elmoCAD\smartFEM\Software\smartFEM\Dokumentation\smartFEM_Models\9s6m_4.mot | Strg+1 |                          | FEM Model                       |  |
| E    | xit   | Alt+F4 | Export Material Contours |                                 |  |
| F    | Parameters  |        | ~                        | Export Steel Materials Contours |  |

#### 1.4 Minimum Symmetry

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

| C PM BLDC           |                        | Topology Filename: CR02b_Embedded_Magnets.top                    |         |       |     | 8 |
|---------------------|------------------------|--|---------|-------|-----|---|
| k ▲/¤77⊙ @・ k ☆ ≻/× |                        | File Edit Magnets Options  |         |       |     |   |
| moca                | Air                    | 50   |         |       |     |   |
| e                   | Magnets<br>Rotor Steel | Types of Rotor: CR02b_Embedded_Magnets                           |         |       | •   | ] |
|                     |                        | Country Court Lenix as   |         |       |     |   |
|                     |                        | Number of magnets  | Nm      | 6     | 1 [ | 1 |
|                     |                        | Outer rotor radius   | Rro     | 15    | mm  |   |
|                     |                        | Inner rotor radius   | Rri     | 5     | mm  |   |
|                     |                        | Pole width   | Wp      | 12    | mm  |   |
|                     |                        | Offset type (OType) {1=Sine 1 period, 2=Sine 1/2 period, 3=Circ} | OType   | 3     |     |   |
|                     |                        | Amplitude(Offset (Amp(Off)                                       | Amp(Off | 0     | mm  |   |
|                     |                        | Height of slot entrance  | Hse     | 1     | mm  |   |
|                     |                        | Slot bottom radius   | Rsb     | 1.36  | mm  |   |
|                     |                        | Pole connecting radius   | Rpc     | 13,36 | mm  |   |
|                     |                        | Distance pocket - rotor surface                                  | Dprs    | 2.2   | mm  |   |
|                     |                        | Pocket height  | Hmp     | 2,5   | mm  |   |
|                     |                        | Strut width  | Wst     | 0,5   | mm  |   |
|                     |                        | Pocket width   | Wmp     | 11    | mm  |   |
|                     |                        | Pocket distance to sector line                                   | Dpsl    | 0,39  | mm  |   |
|                     |                        | Smallest distance pocket - rotor surface                         | Opres   | 0.5   | mm  |   |
|                     |                        | Magnet height  | Hm      | 2.3   | mm  |   |
|                     |                        | Mannet with  | Wm      | 10.7  | mm  |   |

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.

| PM BLDC   |   |
|---|---|
| emocao  | Magnets<br>Rotor Steel<br>Stator Steel<br>Coils |
| Motor Outer Diameter: 53 mm<br>Number of Slots: 9<br>Number of Magnets: 6 |   |
| C Geometry C Material C Nodes   | Models  |

#### 1.5 Parameter

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

| ſ | Ad<br>Wi<br>Wi | ditional slots in teeth feet{0=no, 1=yes}<br>dth of inner air ring<br>dth of outer air ring | As<br>Wiar<br>Woar | - 0<br> 0<br> 0 |
|---|----------------|---|--------------------|-----------------|
|   |                |   |                    |                 |
|   | Ad             | ditional slots in teeth feet{0=no, 1=yes}   | As                 | 1               |
|   | [              | Angle of slots {0 =1 slot, >0 =2 slots}   | AlphaAs            | 0 deg           |
|   |                | Width of slots  | Was                | 1 mm            |
|   |                | Depth of slots  | Das                | 0.5 mm          |
|   | 6              | Entrance type of slots (1=parallel, 2=radial)   | AsType             | 1               |
|   | Wi             | dth of inner air ring   | Wiar               | 0               |
|   | Wi             | dth of outer air ring   | Woar               | 0               |

#### 1.6 Release number

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

| File Edit Magnets Options        |              |      |     |    |      |
|----------------------------------|--------------|------|-----|----|------|
| 9 (*                             |              |      |     |    |      |
| Types of Rotor: CR01b_Surface_Mo | ount_Magnets |      |     |    | •    |
| Geometry Basic Elements          |              |      |     |    |      |
| Number of magnets                |              |      | Nm  | 6  | -    |
| Outer rotor radius               |              |      | Rro | 15 | mm   |
| Inner rotor radius               |              |      | Rri | 5  | mm 👻 |
|                                  | f            |      | T   |    |      |
|                                  | Apply        | Exit |     |    |      |

#### 1.7 Pre-defined parameter of all topologies

#### 1.7.1 Geometry parameter

| S PM BLDC Topolo    | gy Filename: CS06b_IEC_Based.top         |          | x  |
|---------------------|--|----------|----|
| Types of Stator:    | CS06b_IEC_Based                          |          | •  |
|                     | ○ One Coil Per Slot ④ Two Coils Per Slot |          |    |
| Geometry Basic      | Elements                                 |          |    |
| Number of slots     |  | Ns 9     |    |
| Outer stator radius | 3  | Rso 30   | mm |
| Airgap              |  | g 0,9    | mm |
| Inner stator radius | i -                                      | Rsi 15,9 | mm |

#### Machines with inner rotor

Rotor

| ٠   | Number of magnets             | Nm  | = | 6       |    |
|-----|-------------------------------|-----|---|---------|----|
| •   | Outer radius                  | Rro | = | 15      | mm |
| •   | Inner radius                  | Rri | = | 5       | mm |
| Sta | tor                           |     |   |         |    |
| •   | 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<br>Outer radiu<br>Inner radius  | Nm<br>Rro<br>Rri      | =<br>=<br>= | 12<br>25<br>20           | mm<br>mm       |
|-------------|---|-----------------------|-------------|--------------------------|----------------|
| Sta         | tor   |                       |             |                          |                |
| •<br>•<br>• | Number of slots<br>Width of airgap (on one side)<br>Outer radius (calculated)<br>Inner radius | Ns<br>g<br>Rso<br>Rsi | =<br>=<br>= | 9<br>0,5<br>Rri - g<br>5 | mm<br>mm<br>mm |

#### 1.7.2 Basic parameter

#### All Topologies

UnDo and ReDo button

| Topology Filename: CR01b_Surface_Mount_Magnets.top                                     |         | 23    |
|--|---------|-------|
| File Edit Magnets Options  |         |       |
| 5 (2)  |         |       |
| Types of Rotor: CR01b_Surface_Mount_Magnets Geometry Basic Elements                    |         | T     |
| Basic node angle   | Bna     | 1 deg |
| Decimal places   | Dp      | 2     |
| Scaling factor   | Sf      | 1     |
| Priority {0=Node Distance Factor, 1=Number of Segments}                                | NdPrio  | 0     |
| Type of help line text<br>{0=parameter name, 1=value, 2=name+value, 3=name+value+unit} | HItType | 0     |

- 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 |
|----------|------------|
| <i>,</i> | ropologiou |

| Topology Filename: CR01b_Surface_Mount_Magnets.top   |         |            | ×               |
|--|---------|------------|-----------------|
| File Edit Magnets Options  |         |            |                 |
| 1 m m  |         |            |                 |
|  |         |            |                 |
| Types of Rotor: CR01b_Surface_Mount_Magnets  |         |            | -               |
| Geometry Basic Elements  |         |            |                 |
|  |         |            |                 |
| Display all elements   |         | 0          |                 |
| Line No.   | L       | 11         |                 |
| Node distance factor   | Ndist   | 1          |                 |
| Factor for nonlinear node distance $\{-1 \le fact. \le 1\}$  | Nlin    | 0          |                 |
| Number of segments   | Nseg    | 15         |                 |
| Length   | I.      | 4          | mm              |
| Angle  | α       | 90         | deg             |
| Start Point  | P1      | 26         |                 |
| End Point  | P2      | 11         |                 |
| Arc No.  | А       | 7          |                 |
| Node distance factor   | Ndist   | 1          |                 |
| Factor for nonlinear node distance $\{-1 \le fact. \le 1\}$  | Nlin    | 0          |                 |
| Number of segments   | Nseg    | 24         |                 |
| Radius   | r       | 13         | mm              |
| Apex angle   | α       | 27,5       | deg             |
| Length   | 1       | 6,24       | mm              |
| Center Point   | P0      | 0          |                 |
| Start Point  | P1      | 4          |                 |
| End Point  | P2      | 11         |                 |
| Curve No.  | С       | 0          |                 |
| Area No.   | Ar      | 2          |                 |
| Material {0=air, 1=steel, 2=magnet, 3=coil}  | Mat     | 1          |                 |
| Material No. {1<=MatNo<=9}   | MatNo   | 1          |                 |
| Length in z-direction  | Lz/Lmot | 100        | %               |
| Point No.  | Р       | 22         |                 |
| Total number of points {-1=set/reset display always}<br>(mirrored point number = point number + 100) |         | 100        |                 |
| тч<br>тч   |         | 22         |                 |
| X-Coordinate   | x       | 2,85       | mm              |
| Y-Coordinate   | У       | 10,63      | mm              |
| Radius   | r       | 11         | mm              |
| Angle  | α       | 75         | deg             |
| P2   |         | 0          |                 |
| P3   |         | 0          |                 |
|  |         |            |                 |
| Apply Exit   |         |            |                 |
|  |         |            |                 |
|  | То      | pology Rel | ease 55-222 .:: |

For areas which are defined as "Magnet" (Mat=2) is the parameter "MagAngle" displayed. It indicates the direction of magnetization (north pole).

| Area No.   | Ar 1           |
|--|----------------|
| Material {0=air, 1=steel, 2=magnet, 3=coil}                        | Mat 2          |
| Material No. {1<=MatNo<=9}   | MatNo 1        |
| Magnetisation Angle {0<=angle<360°, -888=calculated default value, | MagAngle90 deg |
| -355=perpendicular to the longest side/<br>Point No.               | P 20           |

#### MagAngle can be changed:

- 0 <= MagAngle < 360°mech user defined</li>
   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



#### 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

| $\square$ | "Select Mode"                        | → | leave "Edit Mode", if selected before   |
|-----------|--------------------------------------|---|---|
|           | "Measure Distance Between<br>Points" | → | measurement of the distance between two positions selected with right mouse button. |

"Edit Mode" after selection of one of the following ToolTipButtons

| $\mathbf{Z}$                  | "Add Line"           | → | add a line  |
|-------------------------------|----------------------|---|---|
|                               | "Add Rectangle"      | → | add a rectangle   |
| 2                             | "Add Arc"            | → | add an arc (Pcen, Psta, Pend)   |
| 7                             | "Add Arc"            | → | add an arc (Psta, Pend, Radius)   |
| $\overline{oldsymbol{\circ}}$ | "Add Circle"         | → | add a circle  |
| Q                             | "Add Tangent Circle" | → | add a tangential circle (between line-line, line-<br>arc or arc-arc)                                      |
| <b>(</b>                      | "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   |
| R                             | "Select Point"       | → | select a point in order to change its xy-<br>coordinates  |

| x                  | "Split All Intersections"         | → | split all arcs and lines at their intersection points |
|--------------------|-----------------------------------|---|---|
| $\mathbf{\lambda}$ | "Split Element at Intersection"   | → | split one element at its intersection                 |
|                    | "Split Element At Mouse Position" | → | split an element at mouse position                    |
| X                  | "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.

|                       | )                        | ( -   |         |       |                 |
|-----------------------|--------------------------|---|---------|-------|-----------------|
| O PM BLDC             |                          | Topology Filename: CR01b_Surface_Mount_Magnets                            |         |       | ×               |
| k ≥ / 7 ⊙ ¤ · k x / × |                          | File Edit Magnets Options   |         |       |                 |
| almocao               |                          | Types of Rotor: CR01b_Surface_Mount_Magnets Geometry Basic Benerits       |         |       | •               |
|                       |                          | Number of magnets   | Nm      | 6     |                 |
|                       |                          | Outer rotor radius  | Rro     | 15    | mm              |
| K                     | $\sum$                   | Inner rotor radius  | Rri     | 5     | mm              |
| $\left\{ \right\}$    |                          | Magnet bottom {1=Line, 2=Arc}   | MbType  | 1     |                 |
| VVm                   | $\rightarrow \checkmark$ | Magnet side {1=Radial, 2=Parallel, 3=Parallel+parallel slot sides (Ds<0)} | MsType  | 1     |                 |
|                       |                          | Inter magnet connection {1=Line, 2=Arc}                                   | ImcType | 2     |                 |
|                       |                          | Radius of inner magnet corner   | Rmci    | 12,99 | mm              |
|                       |                          | Inner magnet radius   | Rmi     | 11,52 | mm              |
|                       |                          | Height of magnet  | Hm      | 3,48  | mm E            |
|                       |                          | Width of magnet   | Wm      | 12    | 12 <sub>m</sub> |
|                       |                          | Angular span of magnet  | AlphaM  | 55    | deg             |
|                       |                          | Distance magnet - sector line   | Dmsl    | 0,57  | mm              |
|                       |                          | Offset type {1=Sine, 2=Sine 1/2p, 3=Arc, 4=Line}                          | OffType | 3     |                 |
|                       |                          | Offset {Sine=Amplitude, Arc=±Offset}                                      | AmpIOff | 0     | mm              |

• 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.

| PM BLDC  | Topology Filename: CR01b_Surface_Mount_Magnets  |
|--|---|
| k k / □770 Ø · k x k / X   | File Edit Magnets Options   |
|  | File       Edit       Magnets       Options         Types of Rotor:       CR01b_Suface_Mount_Magnets       ▼         Geometry       Basic       Benerits         Display all elements       20         Line No.       L       0         Arc No.       A       0         Curve No.       A       0         Curve No.       Ar       0         Interver point number of points (-1+set/reset display points always)       Npt       100         P2       0       93       0         User Defined Element (-1+set/reset display points always)       2       2 |
| x=2.6252mm, y=4.2016mm, Radius=4.9543mm, Angle=58.0027<br>Plots<br>G Geometry C Material C Nodes<br>C Rotor C Stator C Model C Complet + | ApplyExit   |
| AddLine: define the 1. point of the line by right mouse click  | Topology Release 59-250;  |

- 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.





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"

- "Split All Intersections"
- "Split Element At Intersection"
- "Split At Mouse Position"
- "Delete Element"

for adaption of xy-coordinates respectiveley radii and angle of user defined points.

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- split all arcs and lines at all intersections.
- split single arcs and lines at intersections.
  - split single arcs and lines at mouse position.
  - 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"

| Topology Filename: CR04b_Embedded_Magnets_3Arcs.top | × |
|---|---|
| File Edit Magnets Options                           |   |
| 5 6   |   |
|   |   |
| Types of Rotor: CR04b_Embedded_Magnets_3Arcs        | - |
| CR_CADdata  |   |
| Geometry Basic CR02b_Embedded_Magnets               | E |
| CR03b_Embedded_Magnets_NoOffset                     |   |

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







#### 2.2 Inner Rotor Topologies

#### 2.2.1 CR01b\_Surface\_Mount\_Magnets



Possible geometries as result of parameter changes



Connection Magnet-Magnet:



Line or Arc

#### 2.2.2 CR02b\_Embedded\_Magnets

| O PM BLDC | • •                    | PM BLDC Topology Filename: CR02b_Embedded_Magnets.top                                   | <u>x</u>     |
|-----------|------------------------|---|--------------|
| elmoca    | Magnets<br>Rotor Steel | Types of Rotor: CR02b_Embedded_Magnets           Geometry         Basic         Bements | •            |
|           |                        | Number of magnets   | Nm 6         |
|           |                        | Outer rotor radius  | Rro 15 mm    |
|           |                        | Inner rotor radius  | Rri 5 mm     |
|           |                        | Pole width  | Wp 12 mm     |
|           |                        | Offset type (OType) {1=Sine 1 period, 2=Sine 1/2 period, 3=Circ}                        | OType 3      |
|           |                        | Amplitude Offset (Amp Off)  | AmplOff 0 mm |
|           |                        | Height of slot entrance   | Hse 1 mm     |
|           |                        | Slot bottom radius  | Rsb 1,36 mm  |

Possible geometries as result of parameter changes

Offset Type:



2.2.3 CR03b\_Embedded\_Magnets\_NoOffset



#### 2.2.4 CR04b\_Embedded\_Magnets\_3Arcs

| PM BLDC |                        | PM BLDC Topology Filename: CR04b_Embedded_Ma                        | agnets_3Arcs.to | p x      |
|---------|------------------------|---|-----------------|----------|
| elmocao | Magnets<br>Rotor Steel | Types of Rotor: CR04b_Embedded_Magnets_3Arcs Geometry Basic Bements |                 | •        |
|         |                        | Number of magnets   | Nm 6            | <b>^</b> |
|         |                        | Outer rotor radius  | Rro 15          | mm       |
|         |                        | Inner rotor radius  | Rri 5           | mm       |
|         |                        | Pole width  | Wp 12           | mm       |
|         |                        | Central arc width   | Wca 10          | mm       |
|         |                        | Central arc radius  | Rca 12          | mm       |
|         |                        | Peripheral arc depth  | Dpa 2           | mm       |
|         |                        | Peripheral arc radius   | Rpa 2,23        | mm       |
|         |                        |   |                 | -        |

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











#### 2.2.12 CR19\_V\_Magnets



#### 2.2.13 CR20d\_V\_Magnets





Possible with or without bar between the magnets

| PM BLDC |                        | Topology Filename: CR21a_Triple_V_Magnet.top                  |       |      | X     |
|---------|------------------------|---|-------|------|-------|
|         |                        | File Magnets  |       |      |       |
| elmocas | Magnets<br>Rotor Steel | Types of Rotor: CR21a_Triple_V_Magnets Geometry Basic Bemerts |       |      | •     |
|         |                        | Number of magnets   | Nm    | 8    |       |
|         |                        | Outer rotor radius  | Rro   | 15   | mm    |
|         |                        | Inner rotor radius  | Rri   | 8    | mm    |
|         |                        | Magnet height   | Hm    | 0,6  | mm    |
|         |                        | Magnet width  | Wm1   | 1,74 | mm    |
|         |                        |   | Wm2   | 2,57 | mm    |
|         |                        |   | Wm3   | 3,41 | mm    |
|         |                        | Inner magnet angle  | Psi   | 15   | deg ≡ |
|         |                        | Radial distance between magnets                               | Dbm   | 0,5  | mm    |
|         |                        | Width of inner strut  | Wsti  | 0,9  | mm    |
|         |                        | heldth of outpricter attrict                                  | W/sto | 0.3  |       |

#### 2.2.14 CR21a\_Triple\_V\_Magnets

#### 2.2.15 CR22b\_Ring\_Magnet







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

#### 😵 PM BLDC PM BLDC Topology Filename: CS05b\_Without\_Pole\_Shoe.top X elmocao Stator Steel Coils Types of Stator: CS05b\_Without\_Pole\_Shoe -○ One Coil Per Slot Two Coils Per Slot Geometry Basic Elements Ns 9 Number of slots Outer stator radius Rso 25 mm Airgap g 0,9 mm Inner stator radius Rsi 15,9 mm Slot type {1=parallel tooth sides, 2=parallel slot sides} Stype 1 So/wt 3 Slot/Tooth width

#### 2.3.1 CS05b\_Without\_Pole\_Shoe

Possible with parallel tooth sides or parallel slot sides:



#### 2.3.2 CS06b\_IEC\_Based

| PM BLDC |              | PM BLDC Topolog      | gy Filename: CS06b_IEC_Based.top                    | ×           |
|---------|--------------|----------------------|---|-------------|
| olmocao | Stator Steel | Types of Stator:     | CS06b_IEC_Based                                     | <b>_</b>    |
|         | Colls        |                      | ○ One Coil Per Slot ④ Two Coils Per Slot            |             |
|         |              | Geometry Basic       | Bements   |             |
|         |              | Number of slots      |   | Ns 9        |
|         |              | Outer stator radius  | 8   | Rso 30 mm   |
|         |              | Airgap               |   | g 0,9 mm    |
|         |              | Inner stator radius  |   | Rsi 15.9 mm |
|         |              | Slot opening         |   | So 2 mm     |
|         |              | Centre of slot entre | ance radius {1=slot entrance line, 2=slot mid line} | Cse 2       |
|         |              | Slot entrance heig   | ht  | Hse 0,5 mm  |
|         |              | Dr. Ch.              |   |             |

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

#### 2.3.3 CS07b\_Short\_Teeth

| PM BLDC |                       | PM BLDC Topology Filename: CS07b_Short | _Teeth.top         |
|---------|-----------------------|--|--------------------|
| elmocao | Stator Steel<br>Coils | Types of Stator: CS07b_Short_Teeth     | •                  |
|         |                       | Geometry Basic Elements                | Two Coils Per Slot |
|         |                       | Number of slots                        | Ns 9               |
|         |                       | Outer stator radius                    | Rso 20,5 mm        |
|         |                       | Air gap                                | g 0.9 mm           |
|         |                       | Inner stator radius                    | Rsi 15,9 mm        |
|         |                       | Width of tooth on outer side           | Wt 6 mm            |
|         |                       | Width of yoke minimum                  | Wy_min 2 mm        |

Possible with trapezoidal / parallel sides of the windings



#### 2.3.4 CS08b\_Offset und CS08c\_Offset

| C PM BLDC |                       | PM BLDC Topolo      | gy Filename: CS08b_Offset.top                             |          | ×  |
|-----------|-----------------------|---------------------|---|----------|----|
| elmocqo   | Stator Steel<br>Coils | Types of Stator:    | CS08b_Offset<br>C One Coil Per Slot  • Two Coils Per Slot |          | •  |
|           |                       | Geometry Basic      | Elements  |          |    |
|           |                       | Number of slots     |   | Ns 9     | Â  |
|           |                       | Outer stator radiu  | s   | Rso 26,5 | mm |
|           |                       | Air gap             |   | g 0.9    | mm |
|           |                       | Inner stator radius | 5   | Rsi 15,9 | mm |
|           |                       | Width of tooth      |   | Wt 3     | mm |
|           |                       | Width of yoke       |   | Wy 3.6   | mm |
|           |                       | Slot opening        |   | So 1.6   |    |

### CS08c includes additonal properties compared to CS08b

Offset Type:









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#### 2.3.5 CS09c\_1Phase\_1Coil

| O PM BLDC |                       | Topology Filename: (    | CS09c_1Phase_1Coil.top                 |               | 23 |
|-----------|-----------------------|-------------------------|--|---------------|----|
| moCa      |                       | File Magnets            |  |               |    |
|           | Stator Steel<br>Coils | Types of Stator: C      | S09c_1Phase_1Coil                      |               | •  |
|           |                       | ۹                       | One Coil Per Slot C Two Coils Per Slot |               |    |
|           |                       | Geometry Basic E        | lements                                |               |    |
|           |                       | Number of slots         |  | Ns 2          |    |
|           |                       | Outer stator radius     |  | Rso 0         | mm |
|           |                       | Air gap                 |  | g 0,9         | mm |
|           |                       | Inner stator radius     |  | Rsi 15,9      | mm |
|           |                       | Width of motor          |  | Wm 50         | mm |
|           |                       | Width of yoke 1         |  | Wy1 9.7       | mm |
|           |                       | Width of yoke 2         |  | Wy2 9,7       | mm |
|           |                       | Slot opening            |  | So 3.4        |    |
|           |                       | Slot entrance type {1=  | parallel, 2=radial}                    | SeType 1      |    |
|           |                       | Height of slot entrance | e                                      | Hse 2,3       | mm |
|           |                       | Height of motor         |  | Hmot 61,76508 |    |
|           |                       | y-Position of rotor     |  | Lo 42         | mm |

#### 2.3.6 CS15d\_Parallel\_Slots

| PM BLDC |                       | Topology Filename: CS15d_Parallel_Slots.top | ×           |
|---------|-----------------------|---|-------------|
| moca    |                       | File Magnets                                |             |
|         | Stator Steel<br>Coils | Types of Stator: CS15d_Parallel_Slots       | <b>•</b>    |
|         |                       | C One Coil Per Slot C Two Coils Per S       | ilot        |
|         |                       | Geometry Basic Elements                     |             |
|         |                       | Number of coils                             | Nc 9        |
|         |                       | Outer stator radius                         | Rso 20 mm   |
|         |                       | Air gap                                     | g 0.6 mm    |
|         |                       | Inner stator radius                         | Rsi 15,6 mm |
|         |                       | Outer stator shape {0=Arc 1=Polygon}        | Orsh 0      |
|         |                       | Tooth width                                 | Wt 5,5 mm   |
|         |                       | Slot 1 opening width                        | S1o 1 mm    |
|         |                       | Slot 1 depth                                | S1d 3 mm    |
|         |                       | Slot 2 opening width inside                 | S2oi 0,6 mm |





#### 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).





For the design von 1 and 2phase motors

#### 2.3.11 CS55\_Single\_Wire

| SR Motor   |                       | Topology Filename: CS55_Single_Wire_R05.top                             |       |      | X Y      |
|--|-----------------------|---|-------|------|----------|
| s 🖌  |                       | File Edit Magnets Options   |       |      |          |
| elmocao  | Stator Steel<br>Coils | Types of Stator: CS55_Single_Wire<br>Coils per Stot: C 1 Coil C 2 Coils |       |      | <b>•</b> |
|  |                       | Geometry Basic Bements Number of coils                                  | Nc    | 9    |          |
|  |                       | Outer stator radius   | Rso   | 19,4 | mm       |
|  |                       | Air gap   | g     | 0.6  | mm       |
|  |                       | Inner stator radius   | Rsi   | 15,6 | mm       |
|  |                       | Minimum yoke width  | Wy    | 1,9  | mm       |
|  |                       | Slot opening width  | So    | 0.8  | mm       |
| Plots  |                       | Wire diameter   | Dw    | 1,8  | mm       |
| C Geometry    Material   C Nodes   C Rotor    Stator | C Model C C 🗘         | Number of slots per coil  | Nspc  | 1    | mm       |
|  | •                     | Coil span angle   | Tau_c | 16,2 | deg      |

#### 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:



#### 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



| Topology Filename: CR30_Wound_Field_Winding.top |        |      | ×   |
|---|--------|------|-----|
| File Magnets Options                            |        |      |     |
| Types of Rotor: CR30_Wound_Reld_Winding         |        |      | •   |
| Geometry Basic Elements                         |        |      |     |
| Number of poles                                 | Nm     | 4    | ī Î |
| Outer rotor radius                              | Rro    | 15   | mm  |
| Inner rotor radius                              | Rri    | 5    | mm  |
| Central pole arc (percentage of pole-pitch)     | CParc  | 60   | %   |
| Rotor pole surface radius                       | RRPF   | 13   | mm  |
| Width of pole-shoe                              | WPS    | 15   | mm  |
| Height of pole-shoe                             | HPS    | 3,25 | mm  |
| Pole-shoe edge                                  | PSedge | 0,5  | mm  |
| Radius at pole corner                           | RPC    | 0    | mm  |
| Width of coil-form                              | WCF    | 9,6  | mm  |
| Depth of coil-form                              | DCF    | 3    | mm  |
| Width of field coil-side                        | WFCS   | 2,5  | mm  |

#### 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.

| SR Motor |             | Topology Filename: CR25_Reluctance.top |          |       | ×        |
|----------|-------------|--|----------|-------|----------|
|          |             | File Edit Magnets Options              |          |       |          |
| elmoc 40 | Rotor Steel | Types of Rotor: CR25 Réluctance        |          |       |          |
|          |             | Geometry Basic Elements                |          |       | <u> </u> |
|          |             | Number of poles                        | Np       | 2     |          |
|          |             | Outer rotor radius                     | Rro      | 15    | mm       |
|          |             | Inner rotor radius                     | Rri      | 4     | mm       |
|          |             | Width of pole                          | Wp       | 16,5  | mm       |
|          |             | Angle                                  | Alpha_Wp | 66,73 | mm       |
|          |             | Height                                 | Hp       | 3,6   | mm E     |
|          |             | Inner radius                           | Rpi      | 11,4  | mm       |

#### 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



#### 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.

| Topology Filename: LM02c.tol                |         |       | $\times$ |
|---|---------|-------|----------|
| File Edit Magnets Options                   |         |       |          |
| 5 C   |         |       |          |
| Types of Rotor: LM02c                       |         |       | •        |
| Coils per Slot: C 1 Coil C 2 Coils          |         |       |          |
| Geometry Basic Elements                     |         |       |          |
| Type of Model {0=non-periodic, -1=periodic} |         | -1    | Î        |
| Number of slots / Number of teeth           | Ns / Nt | 6     |          |
| Motor unit width                            | Wmot    | 84 mm |          |
| Stack hight                                 | Hst     | 16 mm |          |
| Yoke width                                  | Yw      | 4 mm  |          |



#### 3.1.2 LM021c

Same as LM02c with enhancements



LM021c as periodic model for loss calculation







#### 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.

| 🙄 PM Linear Motor   |                |                       | Topology Filename: LM10.tol                 |        |    | ×  |
|---|----------------|-----------------------|---|--------|----|----|
| ▶ @ / □ ? ? ⊙ Ø Ø · ħ ☆ ≻ / ×   |                |                       | File Edit Magnets Options                   |        |    |    |
|   |                | Air                   | 50  |        |    |    |
| all to the second se |                | Magnets               |   |        |    |    |
|   |                | Platen Steel          | Types of Rotor: LM10                        |        |    | •  |
|   |                | Forcer Steel<br>Coils | Coils per Slot: C 1 Coil C 2 Coils          |        |    |    |
|   | Periodic Model |                       | Geometry Basic Elements                     |        |    |    |
|   |                |                       |   |        |    | ^  |
|   |                |                       | Type of Model {0=non-periodic, -1=periodic} |        | -1 |    |
|   |                |                       | Number of slots                             | Ns     | 6  |    |
|   |                |                       | Total motor width                           | Wmot   | 84 | mm |
|   |                |                       | Input parameter {0=\v/mu, 1=\v/s}           | Wmu/Ws | 1  |    |
|   |                |                       | Motor unit width                            | Wmu    | 84 | mm |
|   |                |                       | Stator pole width                           | Ws     | 14 | mm |
|   |                |                       | Number of teeth                             | Nt     | 5  |    |
|   |                |                       | Stack hight                                 | Hst    | 16 | mm |

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

| PM Linear Motor                       | - • ×  | Popology Filename: LA04_Actuator.tol                                |         |      | ×  |
|---------------------------------------|--|---|---------|------|----|
| ▶◎/□??⊙@@・き☆≻/×                       |  | File Edit Magnets Options   |         |      |    |
| elmocas                               | Air<br>Platen Steel<br>Forcer Steel<br>Coils | Types of Rotor: LA04_Actuator<br>Colls per Stot: @ 1 Coll C 2 Colls |         |      | T  |
| ······                                |  | Geometry Basic Elements   |         |      |    |
|                                       |  | Width of Stator   | Wstator | 25   | mm |
| · · · · · · · · · · · · · · · · · · · |  | Height of Yoke  | Hy      | 3    | mm |
|                                       |  | Width of slot   | Wa      | 3    | mm |
|                                       |  | Depth of slot   | Ds      | 5    | mm |
|                                       |  | Width of tooth  | Wt      | 5    | mm |
|                                       |  | Width of airgap   | 9       | 0.9  | mm |
|                                       |  | Width of middle airgap layer  | g_ml    | 0.25 | mm |
|                                       |  | Width of mover  | Wmov    | 15   | mm |
| *                                     |  | Height of mover   | Hmov    | 2    | mm |
|                                       |  | Display force path and move vector {0=no, 1=yes}                    |         | 1    | mm |
|                                       |  | Distance between force path and mover                               | dFPM    | 0.15 | mm |
|                                       |  | Length of move vector   | MVIengt | h  6 | mm |

#### 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"*.



#### Presentation in smartFEM after DXF import

| PM Linear Motor  |              | Topology Filename: LA04_Actuator.tol             |         |      | ×  |
|--|--------------|--|---------|------|----|
| <u>▶</u> <b>●</b> / <b>□</b> ? ? ⊙ <b>④ ● ≥</b> <i>k k k k</i> / × |              | File Edit Magnets Options                        |         |      |    |
| Imoca  | Air          | 20   |         |      |    |
| 0  | Platen Steel | Turner of Poter                                  |         |      |    |
|  | Coile        | Types of Notor. [DA04_Actuator                   |         |      | •  |
|  | Colls        | Coils per Slot:                                  |         |      |    |
|  |              | Geometry Basic Elements                          |         |      |    |
|  |              |  |         |      | ~  |
|  |              | Width of Stator                                  | Wstator | 25   | mm |
|  |              | Height of Yoke                                   | Hy      | 3    | mm |
|  |              | Width of slot                                    | Wa      | 3    | mm |
|  |              | Depth of slot                                    | Ds      | 5    | mm |
|  |              | Width of tooth                                   | Wt      | 5    | mm |
|  |              | Width of airgap                                  | g       | 0.9  | mm |
|  |              | Width of middle airgap layer                     | g_ml    | 0,25 | mm |
|  |              | Width of mover                                   | Wmov    | 15   | mm |
| *  |              | Height of mover                                  | Hmov    | 2    | mm |
|  |              | Display force path and move vector {0=no, 1=yes} |         | 1    | mm |
|  |              | Distance between force path and mover            | dFPM    | 0,15 | mm |
|  |              | Length of move vector                            | MVIengt | h  6 | mm |

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