Altair® FluxMotor® 2026

Motor Factory – Windings

General user information

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Contents

1 WINDING

1.1 Overview

In Motor Factory, depending on the considered machine type, there are several types of winding technology:

- 3-Phase classical winding
- Polyphase classical winding
- Hairpin winding
- Field winding
- DC winding

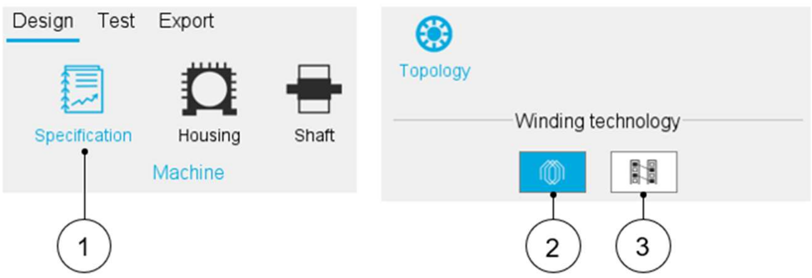
The table below indicates which machines these different types of windings are compatible with.

	Winding types				
	3-Phase classical	n-Phase classical	Hairpin	Field	DC
SM_PM_IR Synchronous Machine with Permanent Magnets - Inner Rotor	✓	✓	✓	✗	✗
SM_PM_OR Synchronous Machine with Permanent Magnets - Outer Rotor	✓	✓	✗	✗	✗
SM_RSM_IR Reluctance Synchronous Machine - Inner Rotor	✓	✗	✓	✗	✗
SM_WF_ISP_IR Wound Field Synchronous Machine Inner Salient Pole – Inner Rotor	✓	✗	✓	✓	✗
IM_SQ_IR Induction Machine with SQuirrel cage - Inner Rotor	✓	✗	✓	✗	✗
IM_SQ_OR Induction Machine with SQuirrel cage - Outer Rotor	✓	✗	✗	✗	✗
DC_PM_IR Permanent Magnet DC machine	✗	✗	✗	✗	✓

1.2 Classical and hairpin windings

1.2.1 Introduction

In Motor Factory, when the classical winding type or the hairpin winding type can be considered, this choice must be done in the Design area, in the environment "Specification".



Classical or hairpin winding technology: how to make the choice ?	
1	In Motor Factory – Design environment – Select the specification – Section "Topology"
2	Classical winding technology
3	Hairpin winding technology

1.2.2 3-Phase and polyphase windings

The polyphase nature of the winding is not an option available in the machine specification. To design a polyphase machine, the user must select the appropriate machine type.
In that case, the winding design environment includes polyphase windings up to 15 phases.

Note: There are many similarities between the 3-Phase and the polyphase windings. That is why it is useful to refer to the explanations and illustrations provided for the “classical winding”. Indeed, most of the examples and images shown for classical winding are for a 3-Phase winding to facilitate comprehension and clarity, since it is the most widely used.

1.2.3 Structural data - Validity domain

The number of slots can be chosen over the range [3, 2400].
The number of poles can be chosen over the range [2, 400].
The number of phases can be chosen over the range [3,15]. Only odd values are considered.

Note: Our process for building and computations has been qualified over the following data ranges:
Range for number of slots [3, 90].
Range for number of poles [2, 80].
Range for number of phases [3,15].

Working beyond these bounds are possible but accuracy of the results is the responsibility of the user.

Three tables representing a selection of combinations of number of poles and number of slots for the most typical number of phases (three, five and seven) are presented below.
In these tables the number of slots goes from n to 90 (with n the number of phases) and the number of poles goes from 2 to 80.

Note:

- For three-phase machines, the grey cells correspond to combinations with a number of slots per pole per phase strictly lower than 0.25. These cases are not allowed by our process.
  Note: if the hairpin winding type is selected only configurations with an integer number of slots per pole and per phase are allowed.

- The black cells correspond to forbidden combinations from a technological point of view.

- The numbers indicated in the other cells correspond to reduction coefficients to the resulting model in Altair® Flux®. For example, “1” means that the whole geometry is represented. “2” means that only half of the machine is represented, and “n” means that the 1/n^th^ of the geometry is represented in the Flux® environment. That means, it gives a general idea of the size of the model in Flux® software. Higher value gives the reduction coefficient and faster computation for a given motor.

	Slots																													
Poles	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90
2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1
4	1	2	1	2	1	2	1	4	1	2	1	2	1	2	1	4	1	2	1	2	1	2	1	4	1	2	1	2	1	2
6			3			3			3			6			3			3			3			6			3			3
8		2	1	4	1	2	1	4	1	2	1	4	1	2	1	8	1	2	1	4	1	2	1	4	1	2	1	4	1	2
10			1	2	5	2	1	2	1	5	1	2	1	2	5	2	1	2	1	10	1	2	1	2	5	2	1	2	1	5
12			3			6			3			6			3			6			3			12			3			6
14				2	1	2	7	2	1	2	1	2	1	7	1	2	1	2	1	2	7	2	1	2	1	2	1	14	1	2
16				4	1	2	1	8	1	2	1	4	1	2	1	8	1	2	1	4	1	2	1	8	1	2	1	4	1	2
18									9									9									9			
20					5	2	1	4	1	10	1	4	1	2	5	4	1	2	1	10	1	2	1	4	5	2	1	4	1	10
22						2	1	2	1	2	11	2	1	2	1	2	1	2	1	2	1	11	1	2	1	2	1	2	1	2
24						6			3			12			3			6			3			12			3			6
26							1	2	1	2	1	2	13	2	1	2	1	2	1	2	1	2	1	2	1	13	1	2	1	2
28							7	4	1	2	1	4	1	14		4	1	2	1	4	7	2	1	4	1	2	1	14	1	2
30									3			6			15			6			3			6			3			15
32								8	1	2	1	4	1	2	1	16	1	2	1	4	1	2	1	8	1	2	1	4	1	2
34									1	2	1	2	1	2	1	2	17	2	1	2	1	2	1	2	1	2	1	2	1	2
36									9									18									9			
38										2	1	2	1	2	1	2	1	2	19	2	1	2	1	2	1	2	1	2	1	2
40										10	1	4	1	2	5	8	1	2	1	20	1	2	1	8	5	2	1	4	1	10
42												6			3			6			21			6			3			6
44											11	4	1	2	1	4	1	2	1	4	1	22	1	4	1	2	1	4	1	2
46												2	1	2	1	2	1	2	1	2	1	2	23	2	1	2	1	2	1	2
48												12			3			6			3			24			3			6
50													1	2	5	2	1	2	1	10	1	2	1	2	25	2	1	2	1	10
52													13	2	1	4	1	2	1	4	1	2	1	4	1	26	1	4	1	2
54																											27			
56														14	1	8	1	2	1	4	7	2	1	8	1	2	1	28	1	2
58															1	2	1	2	1	2	1	2	1	2	1	2	1	2	29	2
60															15			6			3			12			3			30
62																2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
64																16	1	2	1	4	1	2	1	8	1	2	1	4	1	2
66																		6			3			6			3			6
68																	17	2	1	4	1	2	1	4	1	2	1	4	1	2
70																		2	1	10	7	2	1	2	5	2	1	14	1	10
72																		18									9			
74																			1	2	1	2	1	2	1	2	1	2	1	2
76																			19	4	1	2	1	4	1	2	1	4	1	2
78																					3			6			3			6
80																				20	1	2	1	8	5	2	1	4	1	10

Combinations No. poles / No. slots for a three-phase machine

	Slots																	
Poles	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
4	1	2	1	4	1	2	1	4	1	2	1	4	1	2	1	4	1	2
6	1	2	3	2	1	6	1	2	3	2	1	6	1	2	3	2	1	6
8		2	1	4	1	2	1	8	1	2	1	4	1	2	1	8	1	2
10					5					10					5			
12		2	3	4	1	6	1	4	3	2	1	12	1	2	3	4	1	6
14			1	2	1	2	7	2	1	2	1	2	1	14	1	2	1	2
16			1	4	1	2	1	8	1	2	1	4	1	2	1	16	1	2
18			3	2	1	6	1	2	9	2	1	6	1	2	3	2	1	18
20					5					10					5			
22				2	1	2	1	2	1	2	11	2	1	2	1	2	1	2
24				4	1	6	1	8	3	2	1	12	1	2	3	8	1	6
26				2	1	2	1	2	1	2	1	2	13	2	1	2	1	2
28					1	2	7	4	1	2	1	4	1	14	1	4	1	2
30					5					10					15			
32					1	2	1	8	1	2	1	4	1	2	1	16	1	2
34						2	1	2	1	2	1	2	1	2	1	2	17	2
36						6	1	4	9	2	1	12	1	2	3	4	1	18
38						2	1	2	1	2	1	2	1	2	1	2	1	2
40															5			
42							7	2	3	2	1	6	1	14	3	2	1	6
44							1	4	1	2	11	4	1	2	1	4	1	2
46							1	2	1	2	1	2	1	2	1	2	1	2
48								8	3	2	1	12	1	2	3	16	1	6
50																		
52								4	1	2	1	4	13	2	1	4	1	2
54									9	2	1	6	1	2	3	2	1	18
56									1	2	1	4	1	14	1	8	1	2
58									1	2	1	2	1	2	1	2	1	2
60										10					15			
62										2	1	2	1	2	1	2	1	2
64										2	1	4	1	2	1	16	1	2
66										2	11	6	1	2	3	2	1	6
68											1	4	1	2	1	4	17	2
70															5			
72											1	12	1	2	3	8	1	18
74												2	1	2	1	2	1	2
76												4	1	2	1	4	1	2
78												6	13	2	3	2	1	6
80															5			

Combinations No. poles / No. slots for a 5-Phase machine

	Slots												
Poles	7	14	21	28	35	42	49	56	63	70	77	84	91
2	1	2	1	2	1	2	1	2	1	2	1	2	1
4	1	2	1	4	1	2	1	4	1	2	1	4	1
6	1	2	3	2	1	6	1	2	3	2	1	6	1
8	1	2	1	4	1	2	1	8	1	2	1	4	1
10		2	1	2	5	2	1	2	1	10	1	2	1
12		2	3	4	1	6	1	4	3	2	1	12	1
14							7						
16		2	1	4	1	2	1	8	1	2	1	4	1
18		2	3	2	1	6	1	2	9	2	1	6	1
20			1	4	5	2	1	4	1	10	1	4	1
22			1	2	1	2	1	2	1	2	11	2	1
24			3	4	1	6	1	8	3	2	1	12	1
26			1	2	1	2	1	2	1	2	1	2	13
28							7						
30				2	5	6	1	2	3	10	1	6	1
32				4	1	2	1	8	1	2	1	4	1
34				2	1	2	1	2	1	2	1	2	1
36				4	1	6	1	4	9	2	1	12	1
38					1	2	1	2	1	2	1	2	1
40					5	2	1	8	1	10	1	4	1
42							7						
44					1	2	1	4	1	2	11	4	1
46					1	2	1	2	1	2	1	2	1
48						6	1	8	3	2	1	12	1
50						2	1	2	1	10	1	2	1
52						2	1	4	1	2	1	4	13
54						6	1	2	9	2	1	6	1
56							7						
58							1	2	1	2	1	2	1
60							1	4	3	10	1	12	1
62							1	2	1	2	1	2	1
64							1	8	1	2	1	4	1
66								2	3	2	11	6	1
68								4	1	2	1	4	1
70													
72								8	9	2	1	12	1
74								2	1	2	1	2	1
76									1	2	1	4	1
78									3	2	1	6	13
80									1	10	1	4	1

Combinations No. poles / No. slots for a 7-Phase machine

1.2.4 Terminology – Illustration

1.2.4.1 Slot composition - Terminology

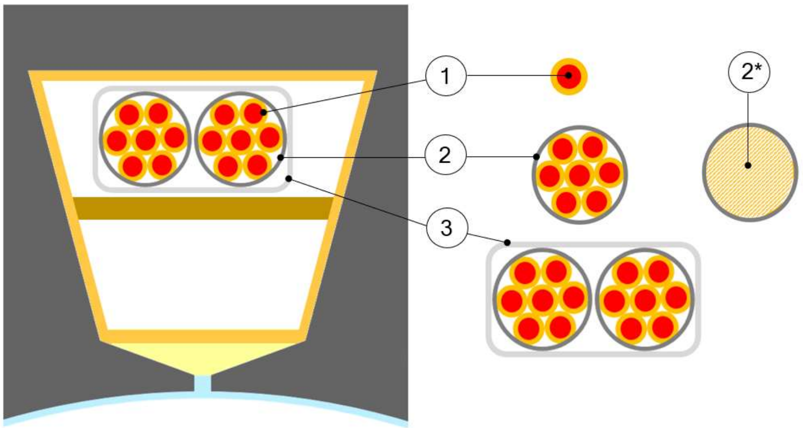
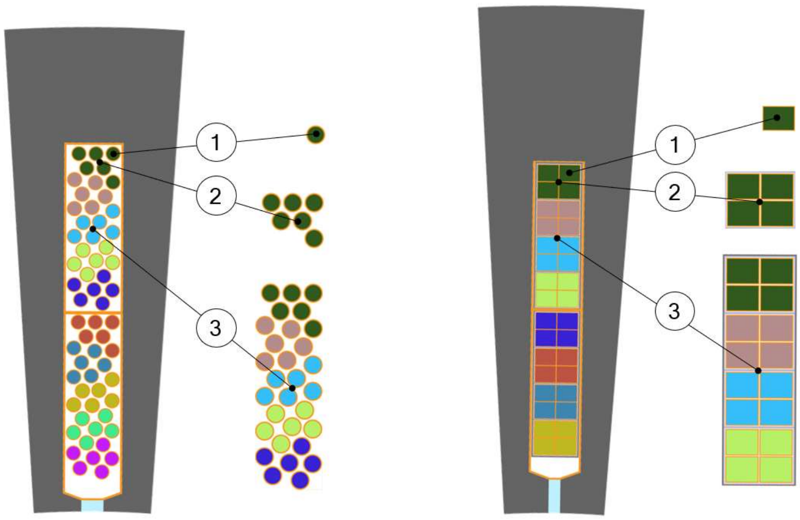


Illustration of the slot composition

1	Wire (also called strand).
2	Conductor, that also corresponds to a turn section (one conductor = one turn). A conductor is composed with one or several wires in parallel (wires in hand).
2*	The hatched area corresponds to the conductor's useful area. Area which includes: the wires + insulation + free space. This is not the conductive area.
3	Coil, which is an assembly of several conductors (i.e. several turns per coil).

1.2.4.2 Slot composition in Motor Factory

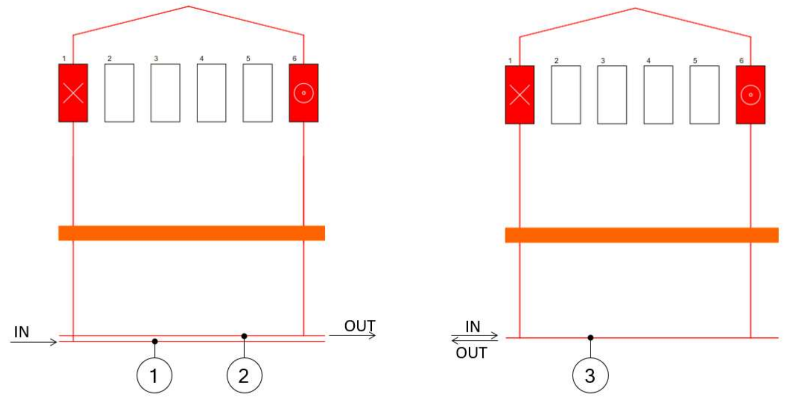


Slot composition – Application in Motor Factory

1	Wire (also called strand)
2	Conductor (also called bundle). That also corresponds to a turn section (one conductor = one turn). A conductor is composed with one or several wires in parallel (wires in hand).
3	Coil, which is an assembly of several conductors (i.e. several turns per coil).

1.2.4.3 Layout of the winding – Winding connections

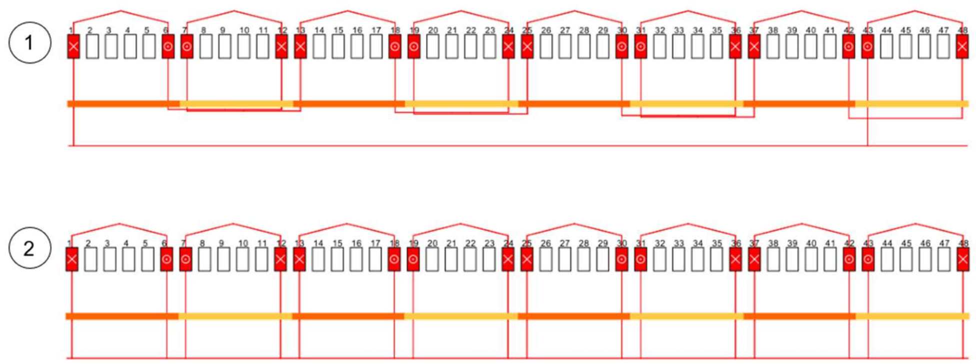
The lines that collect incoming and outgoing connections are merged into a single line. This has been done to make polyphase winding diagrams easier to read. The picture below illustrates the principle of representation.



Representation of the winding connections	
1-2	The two lines connection which represent the incoming and outgoing connections.
3	In the winding layout only one line corresponds to both IN and OUT connections

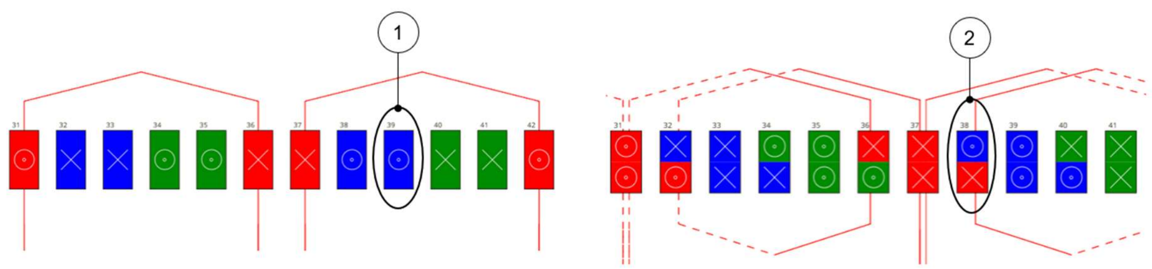
1.2.4.4 Parallel paths

Depending on the number of phases, poles and slots, parallel circuits can be realized in the winding scheme.



Building the winding architecture – The number of parallel paths are represented in the winding scheme	
1	Example where the number of parallel paths is equal to 1.
2	Example where number of parallel paths is equal to 8.

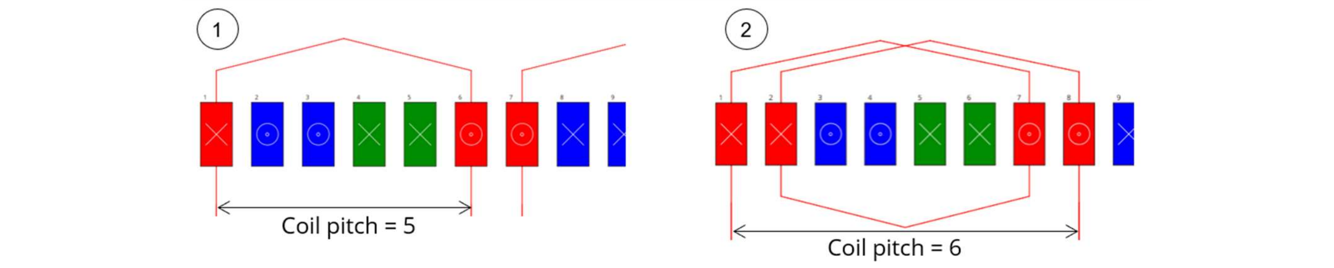
1.2.4.5 Number of layers



Building the winding architecture – The number of layers are represented in the winding scheme	
1	Example, where the number of layers is equal to 1.
2	Example, where the number of layers is equal to 2.

1.2.4.6 Coil pitch

The coil pitch corresponds to the number of teeth between the notch where the coil conductor enters and the notch or coil conductor exits. Here is an Illustration of the coil pitch.

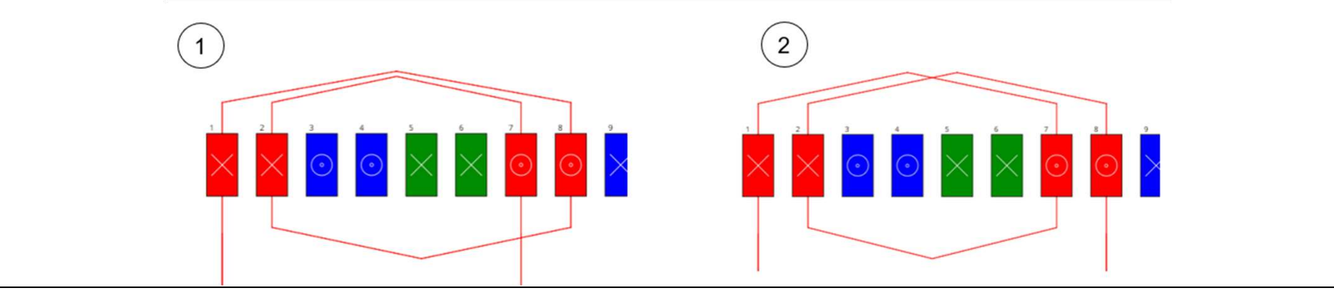


Building the winding architecture – Definition of the coil pitch - (N° Slot return coil) - (N° Slot Go coil)	
1	Example, where the coil pitch is equal to 5 - From slot 1 to slot 6 (6-1 = 5).
2	Example, where the coil pitch is equal to 6 - From slot 1 to slot 7 (7-1 = 6).

1.2.4.7 Winding type

Two winding types are considered: the concentric winding and the lap winding. These two configurations are illustrated below.

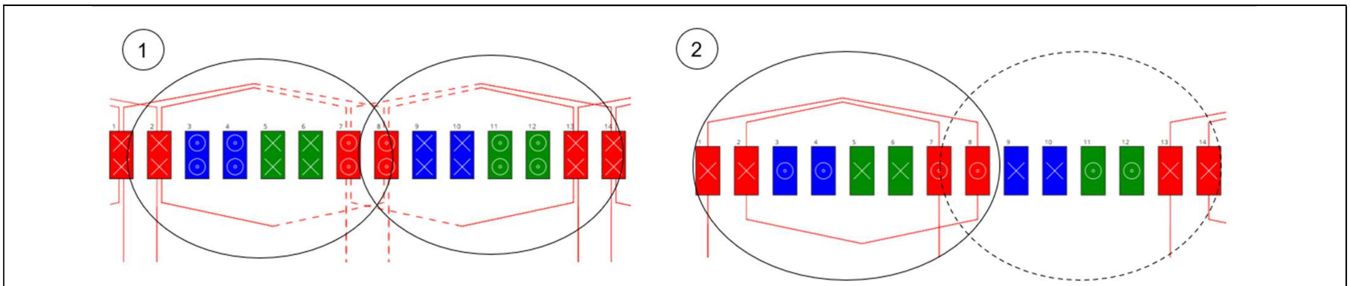
Note: The choice of winding type mainly affects the characteristics of the end winding (particularly their lengths) and also the procedures for mounting the coils in the machine. The distribution of amperes per turn along the machine is not affected by the winding type.



Building the winding architecture – Definition of the winding type: Lap or Concentric	
1	Example for the **Concentric** winding type.
2	Example for the **Lap** winding type.

1.2.4.8 Pole distribution

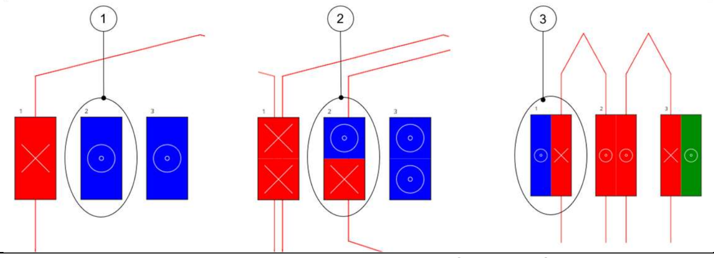
Generally, each pole corresponds to a group of winding coils. However, when a phase has only one group of coils per pair of poles instead of two, the winding is called a consequent pole winding. These two configurations are illustrated below.



Building the winding architecture – Definition of the pole distribution: Per pole or Consequent	
1	Example for the **Per pole** winding type.
2	Example for the **Consequent** winding type.

1.2.4.9 Coil layout in slot

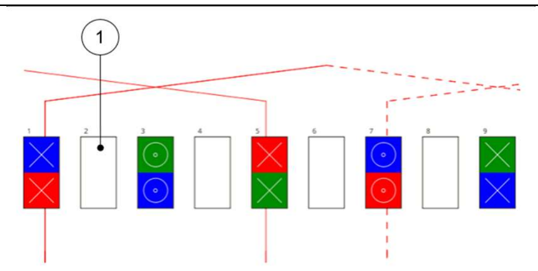
There are three possible coil layouts in slot: Full, superimposed or adjacent. These three configurations are illustrated below.



Building the winding architecture – Definition of coil layout	
1	Example where the coil layout is **Full**.
2	Example where the coil layout is **Superimposed**.
3	Example where the coil layout is **Adjacent**.

1.2.4.10 Winding customization

The customization of the winding scheme is possible by using the advanced or the expert definition mode.
Note: Having more than two layers per slot is not permitted. One or two coils per slot are allowed. Having no layer in certain slots is tolerated. However, in this case, the designer of the machine concerned must ensure that the machine's performance is acceptable. See one illustration below.



Building the winding architecture – Advanced mode The relevance of the winding architecture must be verified by the user	
1	The result is that there are slots without coils. The relevance of the winding architecture depends on the user. A quality criterion allows verifying this relevance. **Note**: Example with 8 poles, 48 slots, coil picth =10

1.2.5 Winding outputs

1.2.5.1 Winding - Characteristics

Label	Symbol	Tooltip, note, formula
No. phases	m	Number of phases
No. poles	p	Number of rotor pole pairs. 2p = number of poles.
No. slots	Nslots	Number of stator slots
No. parallel paths	P_{paths}	Number of parallel paths (all modes).
No. Layers	N_{layers}	Number of layers - 1 or 2 = Maximum number of layers per slot in the machine.
No. conductors per layer		Number of conductors per layer (Hairpin winding technology)
Layer shift		Layer shift in number of slot pitches. Only available with 2 layers. (Hairpin winding technology)
Coil layout	*	Coil layout inside the slot – Full, Superimposed or Adjacent.
Winding connection	Connect	Winding connection (Y – Wye or Δ - Delta)
Winding type	*	The winding type: Lap, Concentric or manual. Note: “Manual” characterizes the “winding type” when the chosen “Winding mode” is “Expert mode”
Current balance of parallel path		Current balance of parallel path – Yes or No (Hairpin winding technology)
Pole distribution	*	Pole distribution – “Per pole” or “Consequent”. Accessible via “Advanced mode”. (Classical winding technology)
No. slots / pole / phase	q	Number of slots per pole and per phase. $q = \frac{Nslots}{2 \times p \times m}$ Where p is the number of pole pairs and m the number of phases.
Pole pitch	τ_{pole-z}	$\tau_{pole-z} = \frac{Nslots}{2 \times p}$ where Nslots is the number of slots and p is the number of pole pairs
Phase sequence	*	Phase sequence i.e. rotation direction of the Magneto-Motive Force (M.M.F.). Clockwise or Counterclockwise (C. Clockwise). The rotation direction is defined when facing the machine on the connection side. Note: Only the clockwise phase sequence is available for the hairpin winding technology.
No. coils / pole / phase	CPP	Number of coils per pole per phase (output data). As output data, CPP is deduced from the analysis of the connection table. It is also a user input available in the advanced mode (Classical winding technology)
Coil pitch	τ_{coil}	Number of slot pitches between coil input and coil output (Easy mode and Advanced mode). For Expert mode, it is not computed because the coil pitch can be equal to different values.

Note: In green information dedicated to the hairpin winding technology, in blue information dedicated to classical winding technology.

1.2.5.2 Winding factors (Fundamental)

Only winding factors corresponding to the fundamental signals are listed below.

Label	Symbol	Tooltip, note, formula
Winding factor	K_W	Winding factor: $K_W = K_{Dist} \times K_{Pitch} \times K_{Skew}$
Distribution factor	K_{Dist}	Distribution factor.
Pitch factor	K_{Pitch}	Pitch factor.
Skew factor	K_{Skew}	Note: Skew factor is computed when the skewing of the stator slots is considered. Without slot skewing this factor is always equal to 1.

Note: For the hairpin winding technology, for unbalanced hairpin configurations, as these results are not relevant, they are not computed and “-“ is displayed instead.
Unbalanced hairpin configurations are characterized by at least one parallel path which is different in term of voltage and impedance from the other parallel paths.

1.2.5.3 Coil

1) Case of classical winding technology

Label	Tooltip, note, formula
No. turns per coil	Number of turns per coil.
No. turns in series per phase	Number of turns in series per phase $$N_{turns} = \frac{N_{coils}}{2 \times P_{paths}}$$ Where N_{coils} is the total number of coils and P_{paths} the number of parallel paths.
No. conductors per phase	Number of conductors per phase = total number of conductors $$N_{coils} = 2 \times (q \times 2 \times p \times Turns)$$ Where p is the number of pole pairs, q is the number of slots per pole per phase, and Turns is the number of turns per coil.

2) Case of hairpin winding technology

Label	Tooltip, note, formula
No. turns per coil	Number of turns per coil is always 1, because a hairpin is defined as a coil.
No. turns in series per phase	Number of turns in series per phase $$N_{turns} = \frac{N_{conductor\ per\ parallel\ path}}{2}$$
No. conductors per phase	$$N_{\frac{conductors}{phase}} = N_{conductor\ per\ parallel\ path} * N_{Parallel\ path}$$

1.2.5.4 Lengths

Label	Tooltip, note, formula
Total conductor length	Total conductor length.
Mean turn length	Mean turn length.
Coil connection length	Additional length corresponding to the connections between coils.
Axial overall length	Axial overall length. Length between the two extremities of the winding i.e. between connection side and opposite connection side.

1.2.5.5 Areas in slot

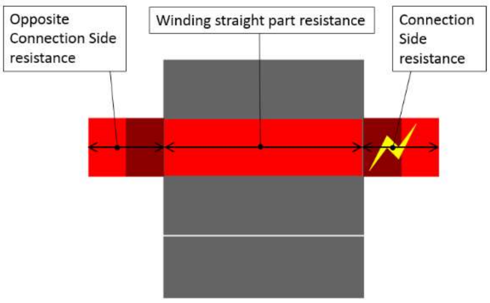
Label	Tooltip, note, formula
Conductive area	Conductive area inside one slot. One considers the slots of the machine where the number of coils are maximum. $$A_{CondSlot} = A_{Cond} \times Turns$$ Where A_{Cond} is the conductor conductive area And Turns is the number of turns per coil
Conductor conductive area	$$A_{Cond} = Nwires \times A_{wire}$$ This area allows to compute the current density. N_{wires} is the number of wires in a conductor, and A_{wire} the Wire conductive area
Wire conductive area	Wire area (without insulation).
Slot area	Slot area.
Insulation area	Insulation area inside one slot. One considers the slots of the machine where the number of coils are maximum.
Free area	$$A_{Free} = A_{Slot} - A_{CondSlot} - A_{InsulSlot}$$ Where A_{Slot} is the Slot area, $A_{CondSlot}$ is the conductive area inside one slot and $A_{InsulSlot}$ is the Insulation area inside one slot.

1.2.5.6 Fill factors

Label	Tooltip, note, formula
Gross fill factor	Gross fill factor. Occupancy rate of the slot (conductive area only). $\frac{Conductor\ conductive\ area}{Slot\ area} \times 100$
Net fill factor	Net fill factor. Occupancy rate of the slot (conductive area + insulation area). $\frac{Conductor\ conductive\ area + insulation\ area}{Slot\ area} \times 100$

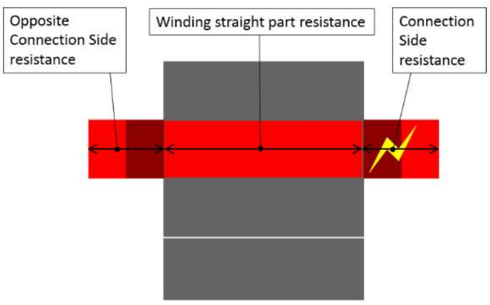
1.2.5.7 Resistance at 20°C and at ref. temperature

1) Case of classical winding technology

Label	Tooltip, note, formula
Phase resistance	Phase resistance
Line-Line resistance	Line-Line resistance
Winding straight part resistance	
End-winding resistance	
Connection side end-winding resistance	
Opposite connection side end-winding resistance	

Note 1: The reference temperature is a user input parameter defined in the winding – X-Factor tab.
Note 2: The connection side end-winding resistance considers the additional length corresponding to the connection between coils.

2) Case of the hairpin winding technology

Label	Tooltip, note, formula
Phase resistance	Phase resistance
Line-Line resistance	Line-Line resistance
Parallel path number	Number of parallel paths
Parallel path resistance	Value of parallel path resistance
Winding straight part resistance	
End-winding resistance	
Connection side end-winding resistance	
Opposite connection side end-winding resistance	

Note 1: The reference temperature is a user input parameter defined in the winding – X-Factor tab.
Note 2: The connection side end-winding resistance considers the additional length corresponding to the connections between coils.
Note 3: For each parallel path, the resistances are computed and displayed for the winding straight part, the end-winding part (at connection side and at opposite connection side)

1.2.5.8 Inductances

1) Case of classical winding technology

Label	Tooltip, note, formula
End winding	Total end winding inductance (including the two sides of the machine).
C.S. end winding	Connection side end winding inductance.
O.C.S. end winding	Opposite connection side end winding inductance.

2) Case of the hairpin winding technology

Label	Tooltip, note, formula
Phase	Phase inductance
Parallel path number	Number of parallel paths
End winding	Total end winding inductance (including the two sides of the machine).
C.S. end winding	Connection side end winding inductance.
O.C.S. end winding	Opposite connection side end winding inductance.

Note: For each parallel path, the end winding inductances are computed and displayed for the Connection Side and for the Opposite Connection Side.

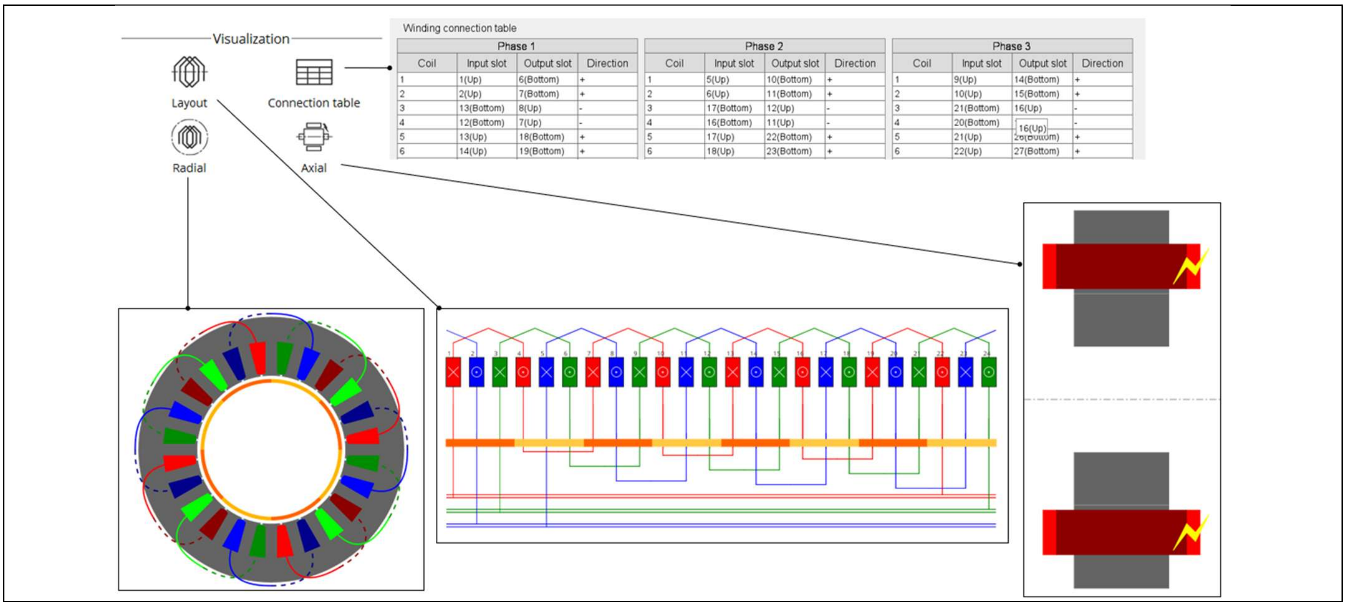
1.2.5.9 Masses and costs

For additional information, refer to the sections dedicated to the coil and conductor settings and End-winding topology.

Label	Tooltip, note, formula
Total	Total winding mass.
Electric conductor	Conductive part mass.
Total insulation	Total winding insulation mass (wire + conductor + coil insulation + liner + phase separator).
Wire insulation	Wire insulation.
Conductor insulation	Conductor insulation.
Coil insulation	Coil insulation.
Liner insulation	Liner insulation.
Phase separator insulation	Phase separator insulation.
Impregnation insulation	Impregnation insulation
C.S. potting	Connection Side potting
O.C.S. potting	Opposite Connection Side potting
Wedge insulation	Wedge insulation, only when the slot topology contains a wedge

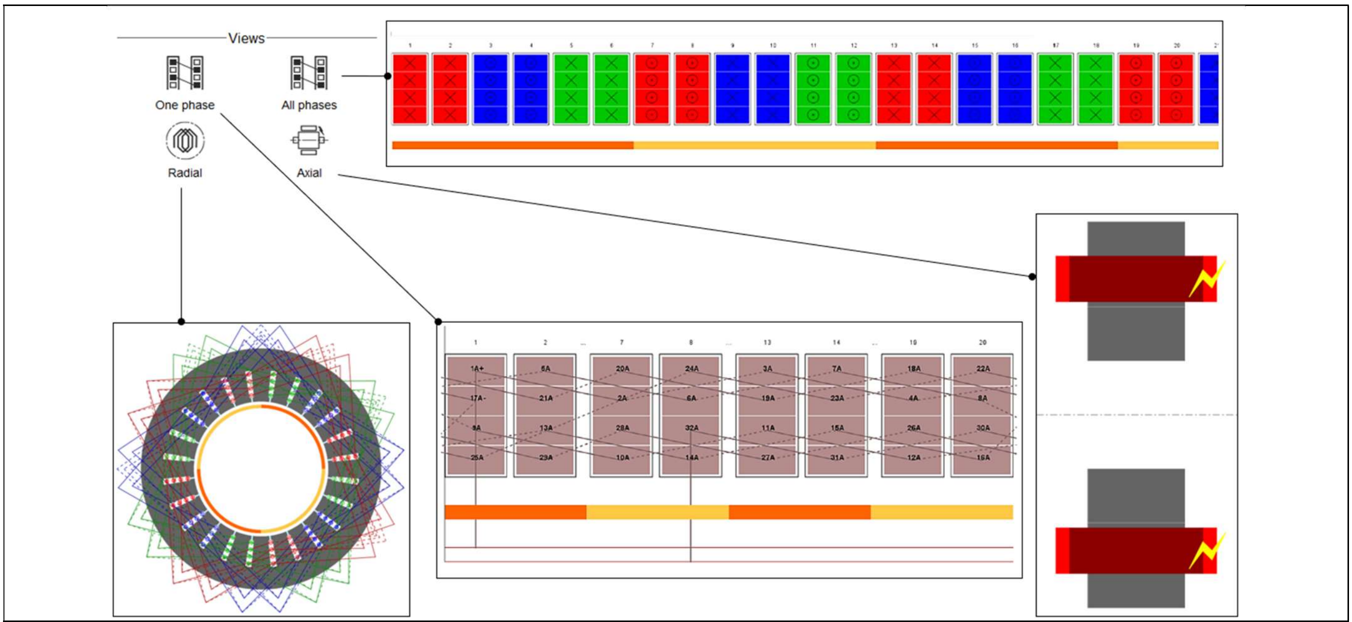
1.2.5.10 Visualization of the winding architecture

1) Case of classical winding technology



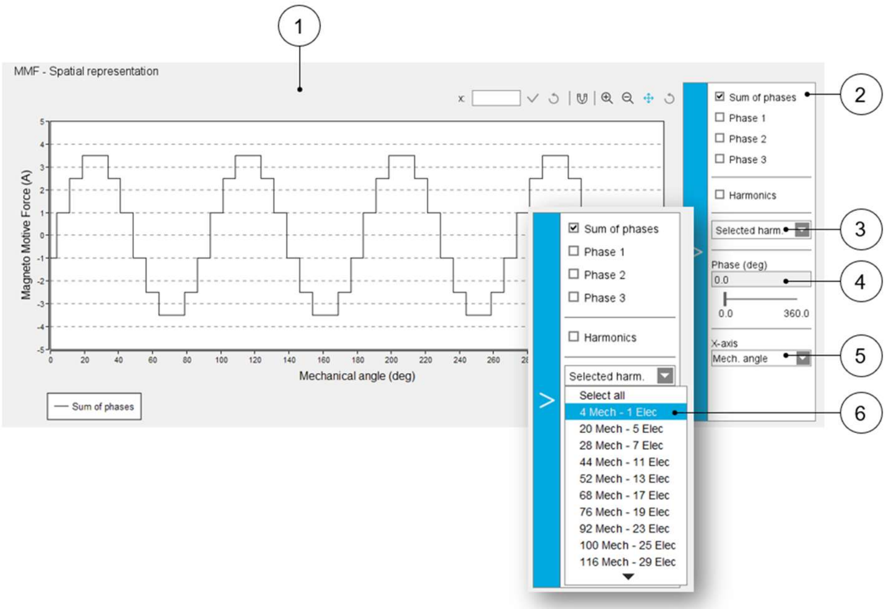
Visualization of the winding architecture

2) Case of the hairpin winding technology

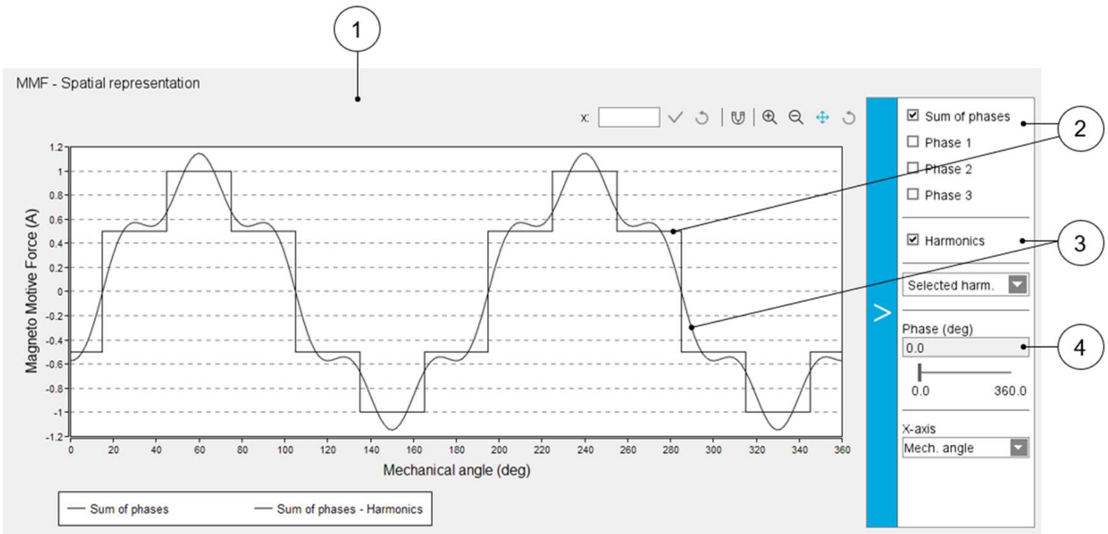


Visualization of the winding architecture

1.2.5.11 Magneto-Motive Force analysis



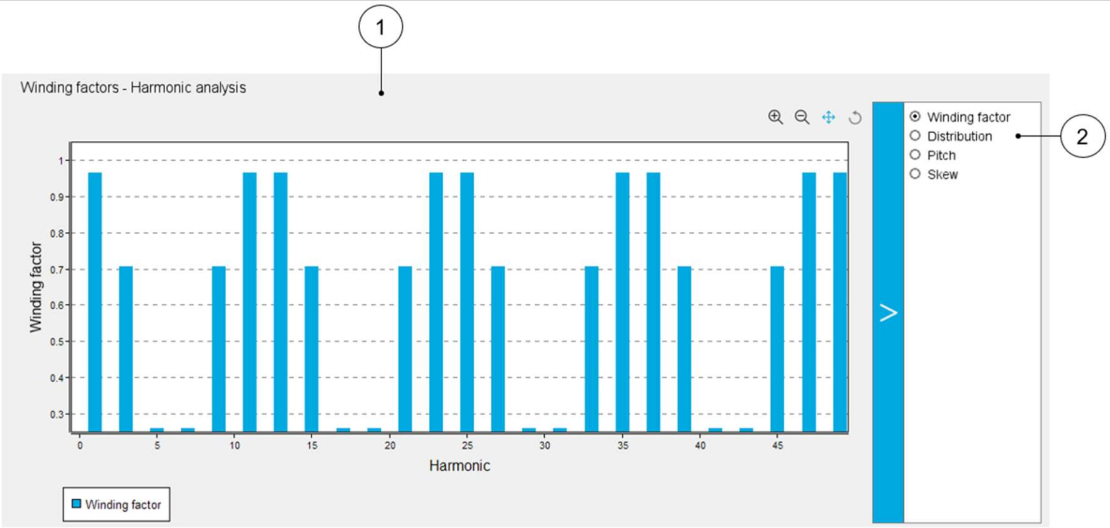
WINDING design area	
1	Select the spatial representation of the Magneto-Motive Force (M.M.F.)
2	Check the curves to display. Sum of phases M.M.F or M.M.F. provided by each phase. Note: Superimposition of harmonics is possible only if one or several harmonics have been selected. See explanation below.
3	Visualize the harmonic list of the M.M.F.
4	Select the phase and make slide the M.M.F. signal. That shows the direction of rotation of the M.M.F... This illustrates the relevance of the phase sequence (user input).
5	Mechanical angle or slot number can be chosen for the X-axis.
6	Select one or several harmonics to superimpose with the original M.M.F. signal.



Superimposition of harmonics to original M.M.F. signal	
1	Select the spatial representation of the Magneto-Motive Force (M.M.F.).
2	Check the curves to display. Sum of phases for example.
3	Check Harmonics. The harmonics previously selected in the M.M.F. harmonic table are superimposed with the original M.M.F. signal.
4	The selected phase is equal to 0.

1.2.5.12 Quality criteria

1) Winding factor



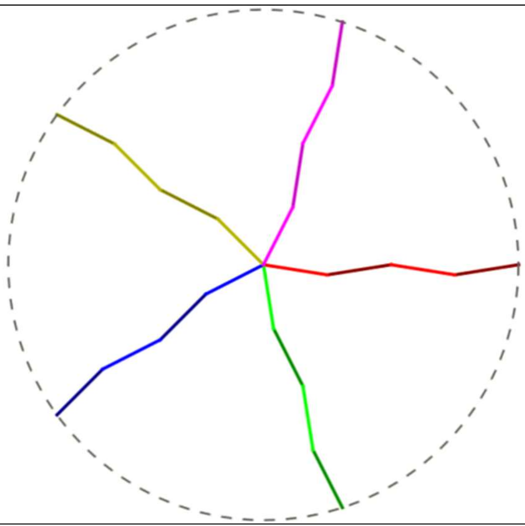
Winding factors

1	Select the winding factor bar-graph.
2	Checking the different winding factors allows visualizing the corresponding bar graph. **Note**: Skew factor is computed when the skewing of the stator slots is considered. Without slot skewing this factor is always equal to 1.

Note: For unbalanced hairpin configurations, as the results are not relevant, therefore, they are not computed and displayed. The unbalanced hairpin configurations are characterized by at least one parallel path which is different in term of voltage and impedance from the other parallel paths.

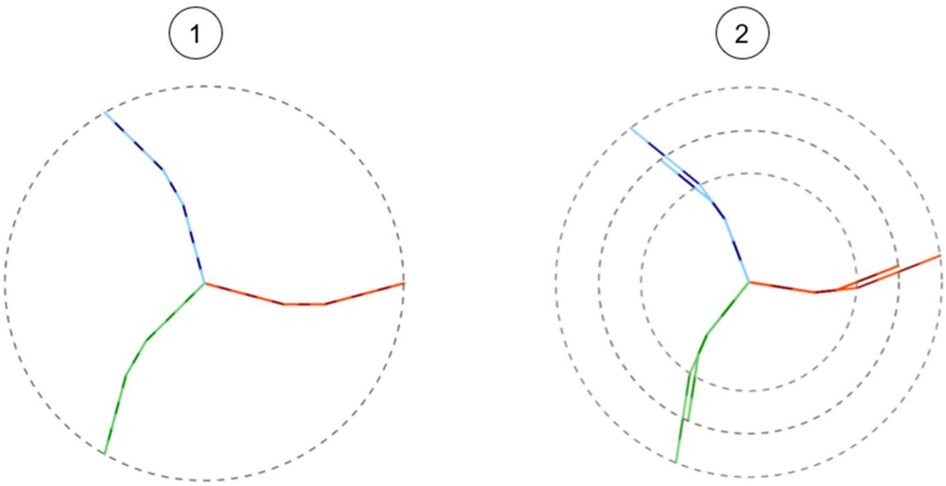
2) Slot star

a) Case of classical winding technology



Star slot. Example for 5-Phase machine	
1	The Slot star represents the total vector summation of voltages at the ends of each coil

b) Case of the hairpin winding technology



Slot star - Strong or weak balance case example	
1	Slot star - Strong or weak balance case example
2	Slot star - Unbalance case example Note: Balance analysis classification: When the hairpin configuration is balanced (strong and weak balance), all the slot stars are superimposed (to differentiate strong and weak balance case referred to the table Parallel paths) When the hairpin configuration is unbalanced, there are as many different slot stars (circles) as there are different unbalanced parallel paths

Note: Definition of Strong and weak balance are done below

3) Current balance of parallel paths

Only applicable for hairpin winding technology

For each slot per pole and per phase of each parallel path, the number of conductors in each conductor layer is computed and displayed in a table

The three kinds of possible configurations in term of electrical current in parallel paths are illustrated below: Strong balance, weak balance and unbalance

Current balance of parallel paths

	// 1		// 2	
	SPP 1	SPP 2	SPP 1	SPP 2
Full: C1	2	2	2	2
Full: C2	2	2	2	2
Full: C3	2	2	2	2
Full: C4	2	2	2	2

	1//	2//
	SPP1 + SPP2	SPP1 + SPP2
Full : C1	4	4
Full : C2	4	4
Full : C3	4	4
Full : C4	4	4

Current balance of parallel paths – Strong balance case example

Current balance of parallel paths

	// 1		// 2		// 3		// 4	
	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2
Full: C1	2	0	2	0	0	2	0	2
Full: C2	2	0	2	0	0	2	0	2
Full: C3	0	2	0	2	2	0	2	0
Full: C4	0	2	0	2	2	0	2	0

	1//	2//	3//	4//
	SPP1 + SPP2	SPP1 + SPP2	SPP1 + SPP2	SPP1 + SPP2
Full : C1	4	4	4	4
Full : C2	4	4	4	4
Full : C3	4	4	4	4
Full : C4	4	4	4	4

Current balance of parallel paths – Weak balance case example

Current balance of parallel paths

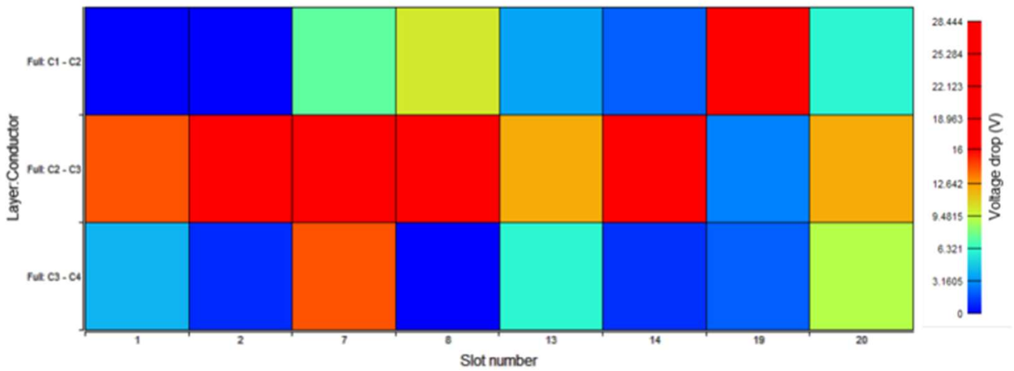
	// 1		// 2		// 3		// 4	
	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2
Full: C1	2	0	2	0	0	2	0	2
Full: C2	2	0	2	0	0	2	0	2
Full: C3	0	1	0	2	2	1	2	0
Full: C4	0	1	0	2	2	1	2	0

	1//	2//	3//	4//
	SPP1 + SPP2	SPP1 + SPP2	SPP1 + SPP2	SPP1 + SPP2
Full : C1	2	2	2	2
Full : C2	2	2	2	2
Full : C3	1	2	3	2
Full : C4	1	2	3	2

Current balance of parallel paths – Unbalance case example

1	Layer of conductors
2	Balance analysis classification: - When the same number of conductors are displayed in all the cells, a “strong balance hairpin configuration” is obtained. This is the best winding design configuration. - If for each parallel path and all layers of conductors the sums of conductors are the same, a “weak balance hairpin configuration” is probably obtained (to be confirmed with the slot star if all the circles are well superimposed). If for each parallel path and all layers of conductors the sums of conductors are different, an “unbalance hairpin configuration” is obtained.

4) Voltage drop



Conductor voltage drop

1	Inside each slot, the voltage drops between the superimposed conductors for calculating the maximum Line-Line voltage value and the voltage drop limit set by the user (X-factor: model evaluation table). This allows the user to visualize quickly where are the hot points from an electrical potential difference point of view.

1.3 DC winding

1.3.1 Terminology and definitions

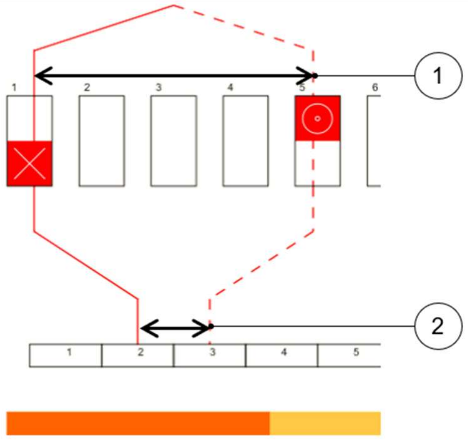
1.3.1.1 Concept

A DC winding is formed by as many individual coils as the number of slots of the machine. All these coils are identical except for an angular shift. Since the coils have an input slot and an output one, a slot will always have two coils wound inside it.

A key characteristic of a DC winding is that, unlike the 3-phase one, a coil is characterized (other by its input and output slots) by the two commutator segments connected to it (one for the input side and a second for the output side). These commutator segments will connect the coil to the brushes and, therefore, to the DC source feeding the machine.

That means that two main variables are needed to fully identify a coil:

- The throw – The coil pitch number of slot pitch between coil input and coil output.
- The commutator pitch: number of commutator segments between the segment connected to the coil input and the segment connected to the coil output.



Graphic example of a reference coil with a throw 4 and a commutator pitch 1
This winding corresponds to a lap winding, simplex with progressive coil connection (see below)

1	Throw
2	Commutator pitch

These two parameters are not chosen randomly but to optimize the electromotive force. Two main types of winding exist: wave winding and lap winding.

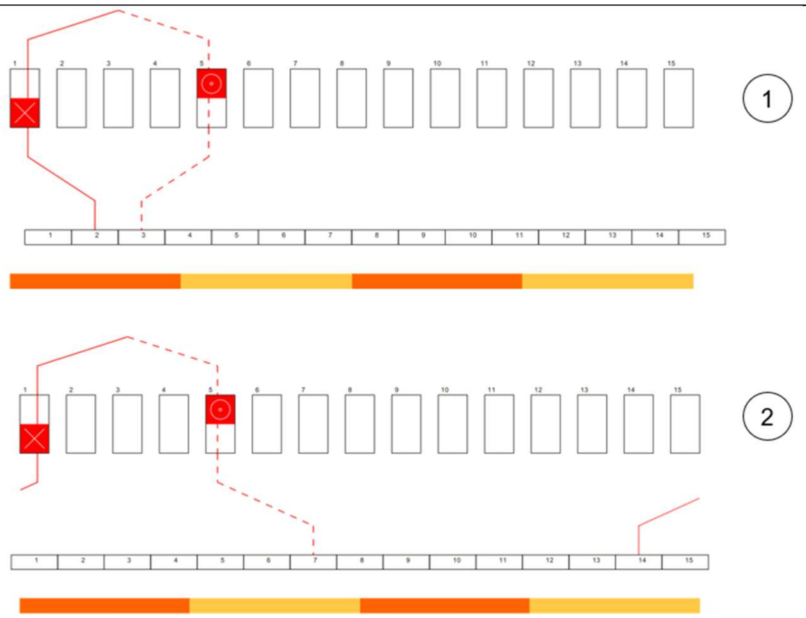
- **Lap winding:** The ends of one coil are connected to consecutive commutation segments (i.e., the commutator pitch absolute value is equal to 1 for simplex winding)
- **Wave winding:** The ends of one coil are connected to commutator segment separated by an angular distance as close as two pole pitch as possible (for simplex winding)

For both winding types, the throw is usually as close as possible to a pole pitch.

Another two important concepts that define a DC winding and are applicable to both wave and lap windings, are the plex and the coil connection.

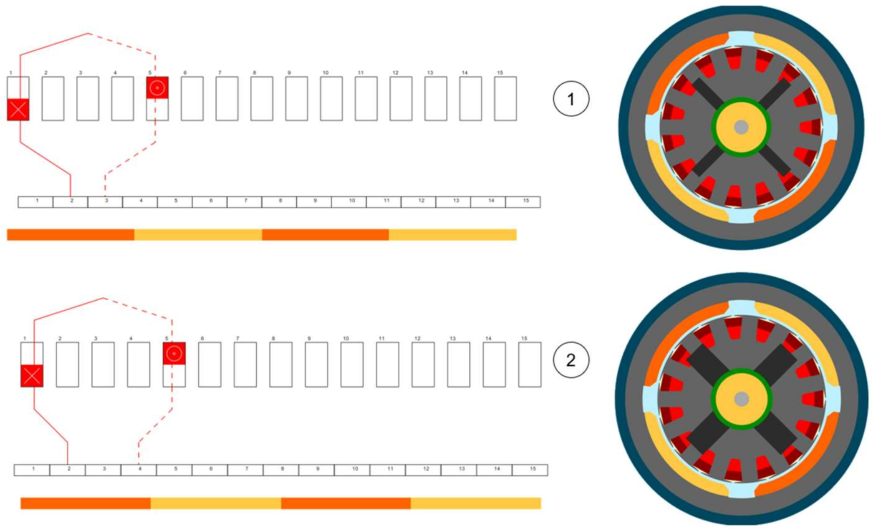
- The plex defines the number of commutator segments in contact with the same brush at a given time. It has a great influence on the number of parallel paths and, therefore, on the machine back EMF and the maximum current.
- The coil connection can be progressive and regressive: In a progressive connection the commutator segments are connected following the same direction as the winding (i.e., commutator pitch is positive) while in a regressive connection the commutator segments are connected following opposite direction as the winding (i.e., commutator pitch is negative).

1.3.1.2 Winding type



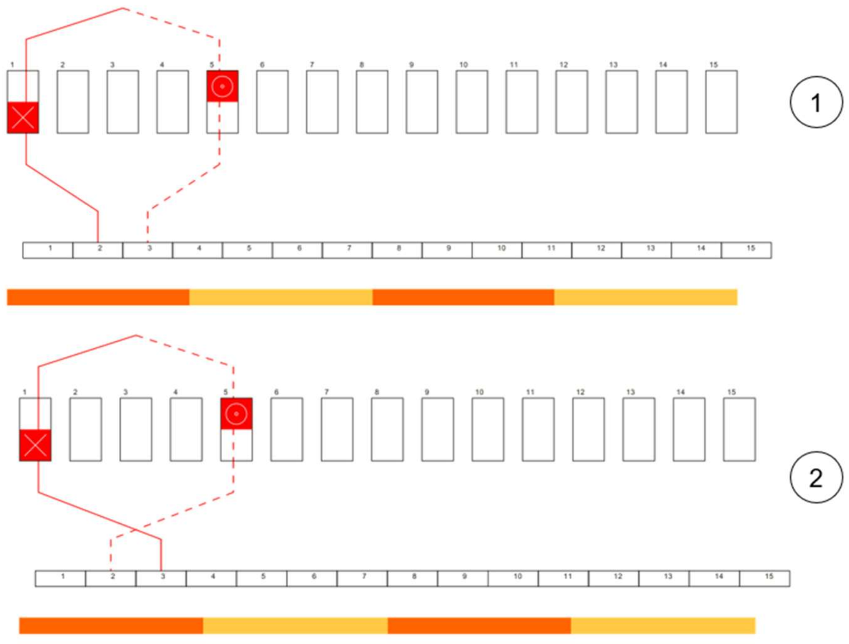
Winding type – Graphical example	
1	Lap winding example
2	Wave winding example

1.3.1.3 Plex



Plex – Graphical examples for a lap progressive winding	
1	Simplex winding
2	Duplex winding

1.3.1.4 Coil connection



Coil connection – Graphical example for lap progressive and regressive winding	
1	Progressive winding
2	Regressive winding

1.3.2 Winding Architecture – Outputs

1.3.2.1 Introduction

Output is quite like 3-phase winding, but some specific parameters arise when dealing with DC machine winding. For shake of completeness the parameters are listed in the tables below.

1.3.2.2 Characterization - Winding

Label	Tooltip, note, formula
No. poles	Number of rotor pole pairs =p. 2p = number of poles.
No. slots	Number of stator slots
No. Layers	Number of layers – For a DC winding it is always equal to 2
Winding type	The winding type: Lap or wave
Plex	The plex (simplex, duplex or triplex)
Coil connection	Connection type: Progressive or regressive Progressive connection: Commutator segments are connected following the same direction as winding (i.e., commutator pitch is positive). Regressive connection: Commutator segments are connecting following opposite direction as winding (i.e., commutator pitch is negative).
Commutator pitch	Number of commutator segments between the segment connected to the coil input and the segment connected to the coil output.
No. parallel paths	Number of parallel paths. For a wave winding it is equal to twice the plex. For a lap winding it is equal to number of poles * plex
Coil layout	Coil layout inside the slot – Full, Superimposed or Adjacent.
Throw (coil pitch)	Number of slot pitch between coil input and coil output.

1.3.2.3 Characterization - Coil

Label	Tooltip, note, formula
No. turns per coil	Number of turns per coil.
No. turns in series	Number of turns in series $N_{turns} = \frac{N_{coils}}{2 \times P_{paths}}$ Where N_{coils} is the total number of coils and P_{paths} the number of parallel paths
No. conductors	Total number of conductors $N_{coils} = 2 \times N_{slots} \times Turns$ Where N_{coils} is the total number of coils and N_{slots} is the number of slots and Turns is the number of turns per coil.

1.3.2.4 Lengths

Label	Tooltip, note, formula
Total conductor length	Total conductor length.
Mean turn length	Mean turn length.
Coil connection length	Additional length corresponding to the connections between coils and commutator segments.
Axial overall length	Axial overall length. Length between the two extremities of the winding i.e. between connection side and opposite connection side.

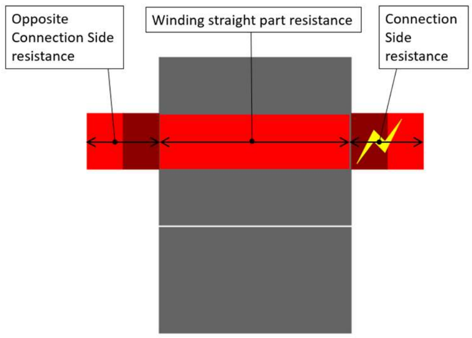
1.3.2.5 Areas in slot

Label	Tooltip, note, formula
Conductive area	Conductive area inside one slot. $A_{CondSlot} = A_{Cond} \times Turns$ Where Turns is the number of turns per coil.
Conductor conductive area	$A_{Cond} = N_{wires} \times A_{wire}$ This area allows to compute the current density.
Wire conductive area	Wire area (without insulation) = A_{wire}
Slot area	Slot area = A_{slot}
Insulation area	Insulation area inside one slot =$A_{InsulSlot}$ One considers the slots of the machine where the number of coils are maximum.
Free area	$A_{Free} = A_{slot} - A_{CondSlot} - A_{InsulSlot}$

1.3.2.6 Fill factors

Label	Tooltip, note, formula
Gross fill factor	Gross fill factor. Occupancy rate of the slot (conductive area only). $\frac{Conductor\ conductive\ area}{Slot\ area} \times 100$
Net fill factor	Net fill factor. Occupancy rate of the slot (conductive area + insulation area). $\frac{Conductor\ conductive\ area + insulation\ area}{Slot\ area} \times 100$

1.3.2.7 Resistances

Label	Tooltip, note, formula
Single coil resistance	Single coil resistance
Parallel path resistance	Resistance of one of the parallel paths
Total resistance	Total resistance of the machine at its terminals
Winding straight part resistance	
End-winding resistance	
Connection side end-winding resistance	
Opposite connection side end-winding resistance	

Note 1: The reference temperature is a user input parameter defined in the winding – X-Factor tab.
Note 2: The connection side end-winding resistance considers the additional length corresponding to the connection between coils and commutator segments.

1.3.2.8 Inductances

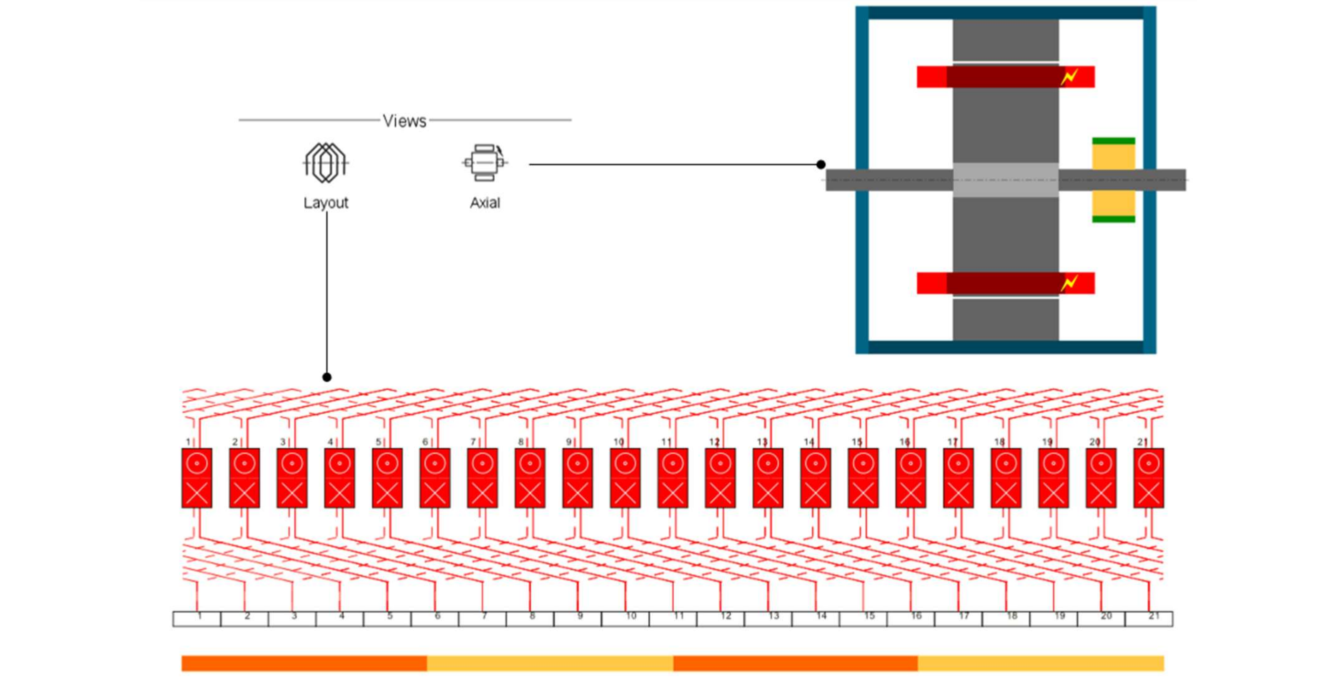
Label	Tooltip, note, formula
End winding	Total end winding inductance (including the two sides of the machine).
C.S. end winding	Connection side end winding inductance.
O.C.S. end winding	Opposite connection side end winding inductance.

1.3.2.9 Masses and costs

For additional information, refer to the sections dedicated to the coil and conductor settings and End-winding topology.

Label	Tooltip, note, formula
Total	Total winding mass.
Electric conductor	Conductive part mass.
Total insulation	Total winding insulation mass (wire + conductor + coil insulation + liner + phase separator).
Wire insulation	Wire insulation.
Conductor insulation	Conductor insulation.
Coil insulation	Coil insulation.
Liner insulation	Liner insulation.
Phase separator insulation	Phase separator insulation.
Impregnation insulation	Impregnation insulation
Wedge insulation	Wedge insulation, only when the slot topology contains a wedge

1.3.2.10 Visualization of the winding architecture



Visualization of the winding architecture

2 CLASSICAL WINDING

2.1 Overview

2.1.1 Design

A scrolling selection bar helps to choose the section in which one can define the winding settings.
Here are the sections available to design the winding step by step:

- "Scheme" to build the winding architecture.
- "Coil" to set how the coil is defined and to see how the slots are filled.
- "Insulation" to define all the winding insulations.
- "End winding" to define the topology and dimensions of the end-windings.
- "X-Factor" to adjust phase resistance and end-winding inductance.
- "Potting" to define the topology and dimensions of the potting around the end-winding.

Note: "Potting" section is available only when the housing is defined with a frame (circular or square shape).

Sections to design the winding step by step

Note: In the software winding datasheet, the parameters written in blue correspond to user input parameters and the parameters written in black correspond to data resulting from computations.

2.1.2 Terminology

Refer to the section "Terminology – Illustration" dedicated to classical and hairpin winding technology.

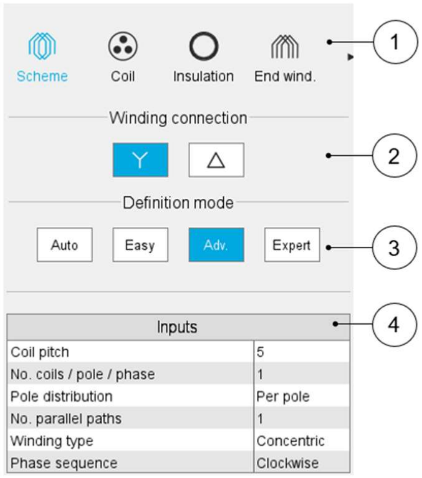
2.1.3 Classical winding outputs

Please refer to the section "Winding / Winding outputs" dedicated to classical and hairpin winding technology.

2.2 Scheme

2.2.1 Overview

Here are below the winding scheme user inputs.

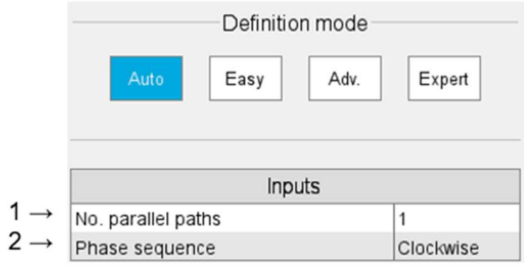


Inputs to define the winding architecture = winding scheme	
1	Sections to design the winding step by step.
2	Winding connection (Y – Wye or Δ - Delta)
3	Winding definition mode: Automatic, Easy, Advanced or Expert. See below section dedicated to the construction of the winding architecture.
4	List of user inputs to define the winding architecture. See the corresponding definition below.

2.2.2 Definition modes

There are four winding definition modes: Automatic, Easy, Advanced or Expert. See below the corresponding illustration.

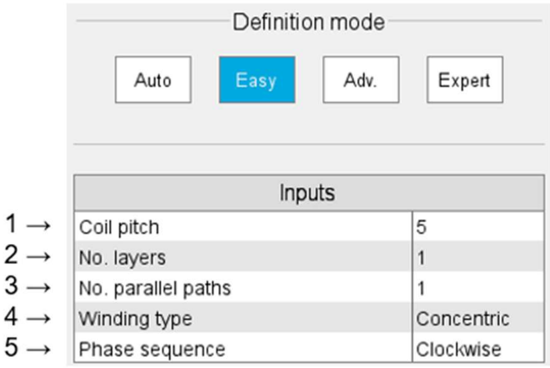
2.2.3 Automatic



Definition mode – **Automatic** mode

1	Phase sequence (all modes). - Clockwise or Counter clockwise. Note: The rotation direction is defined when facing the machine on the connection side.
2	Number of parallel paths (all modes). Note: The possible numbers of parallel paths are automatically computed and proposed to the user. When the user chooses a number of parallel paths, the connections on the winding scheme are automatically updated.

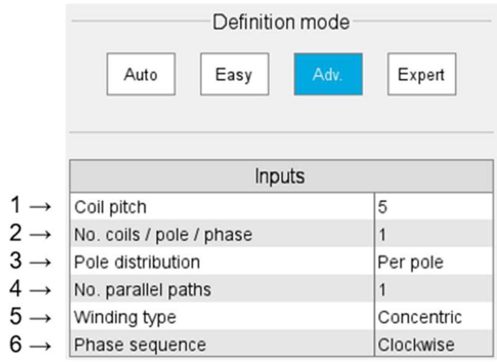
2.2.4 Easy



Definition mode – **Easy** mode

1	Coil pitch = number of slot pitch between coil input and coil output (Easy mode / Advanced mode). Note: The proposed solutions depend on the number of slots, the number of poles and the number of phases. Example 1: With 12 slots,10 poles and 3 phases, only one solution is proposed: a tooth winding. Example 2: With 48 slots, 8 poles and 3 phases, two solutions are proposed: 5 or 6. For various possibilities, a list of solutions is proposed.
2	Number of layers - 1 or 2 (Easy mode). Note: The proposed solutions depend on the number of slots, the number of poles and the number of phases. Example: With 12 slots, 10 poles and 3 phases, only one solution is proposed: 1 layer.
3	Number of parallel paths (all modes). Note: The possible numbers of parallel paths are automatically computed and proposed to the user. When the user chooses several parallel paths, the connections on the winding scheme are automatically updated.
4	Winding type - Lap or Concentric (Easy mode / Advanced mode).
5	Phase sequence (all modes) - Clockwise or Counter clockwise. Note: The rotation direction is defined when facing the machine on the connection side.

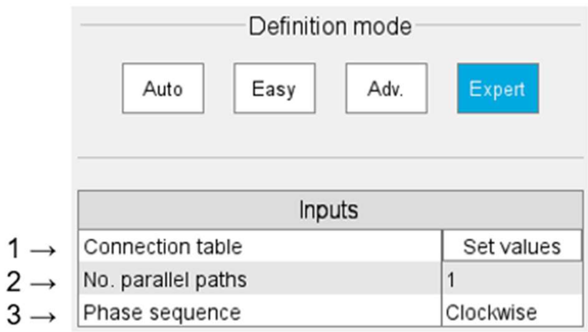
2.2.5 Advanced



Building the winding architecture - **Advanced** mode	
1	Coil pitch = number of slot pitch between coil input and coil output (Easy mode / Advanced mode). Note: The user is free to choose the value they want. The possible solutions depend on the number of slots, the number of poles and the number of phases.
2	Definition of the number of coils per pole and per phase.
3	Definition of the pole distribution: Per pole or Consequent.
4	Number of parallel paths (all modes). Note: The possible numbers of parallel paths are automatically computed and proposed to the user. When the user chooses several parallel paths, the connections on the winding scheme are automatically updated.
5	Winding type - Lap or Concentric (Easy mode / Advanced mode).
6	Phase sequence (all modes) - Clockwise or counter clockwise. Note: The rotation direction is defined when facing the machine on the connection side.

2.2.6 Expert

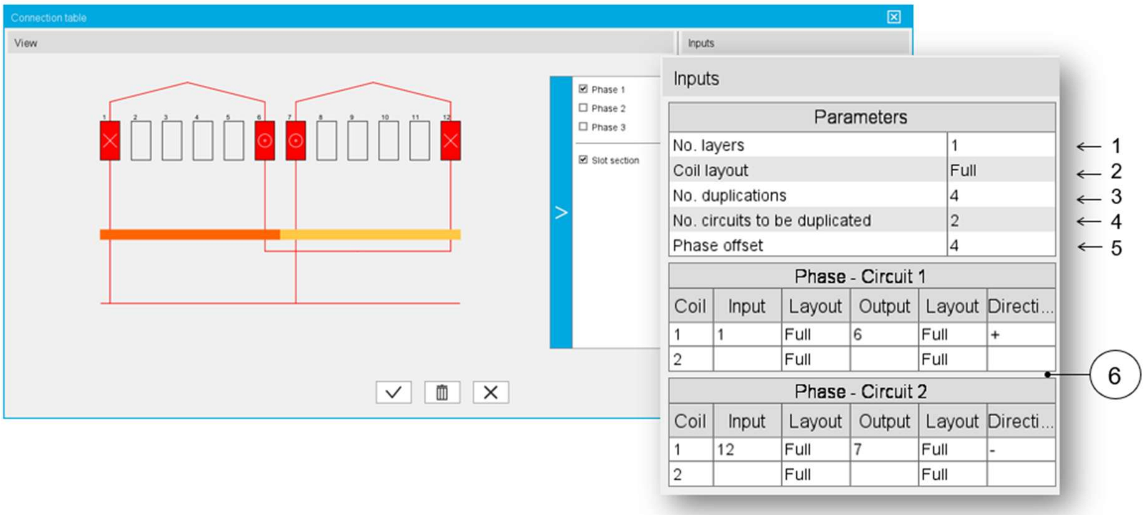
2.2.6.1 Presentation



Inputs to define the winding architecture = **Expert** mode	
1	"Set values" means opening the dialog box to fill the connection table. See the table connection below.
2	Number of parallel paths. The possible numbers of parallel paths are automatically computed and proposed to the user. When the user chooses several parallel paths, the connections on the winding scheme are automatically updated. See examples in Auto mode chapter. **Note:** The complete list of the possible numbers of parallel paths is proposed. Sometimes, the number of parallel paths can be greater than the number of possible duplications. In that case, the connection of the parallel paths is not displayed on the layout of the winding.
3	Phase sequence (all modes) - Clockwise or counter clockwise. Note: The rotation direction is defined when facing the machine on the connection side.

2.2.6.2 Connection table

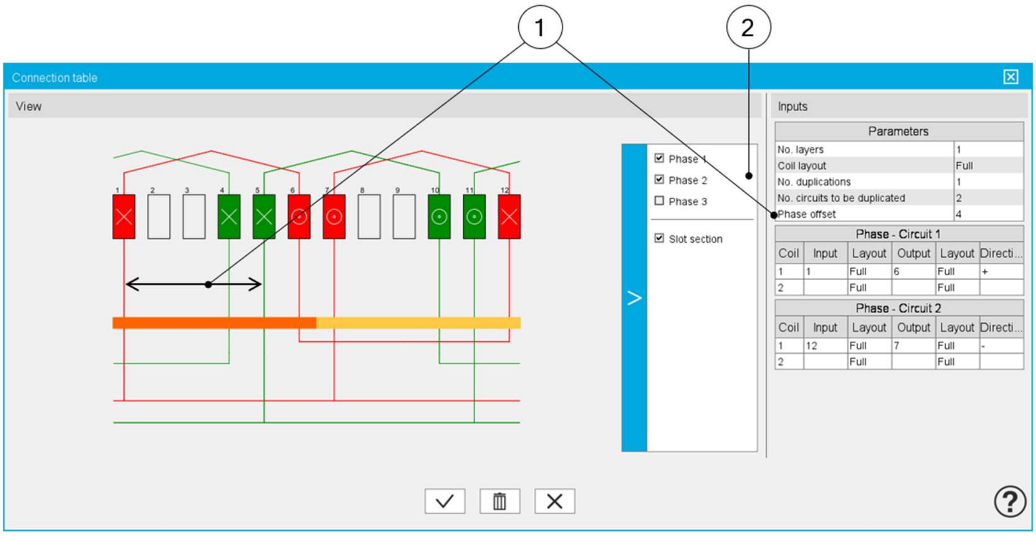
1) Input parameters



Building the winding architecture – Filling of the connection table

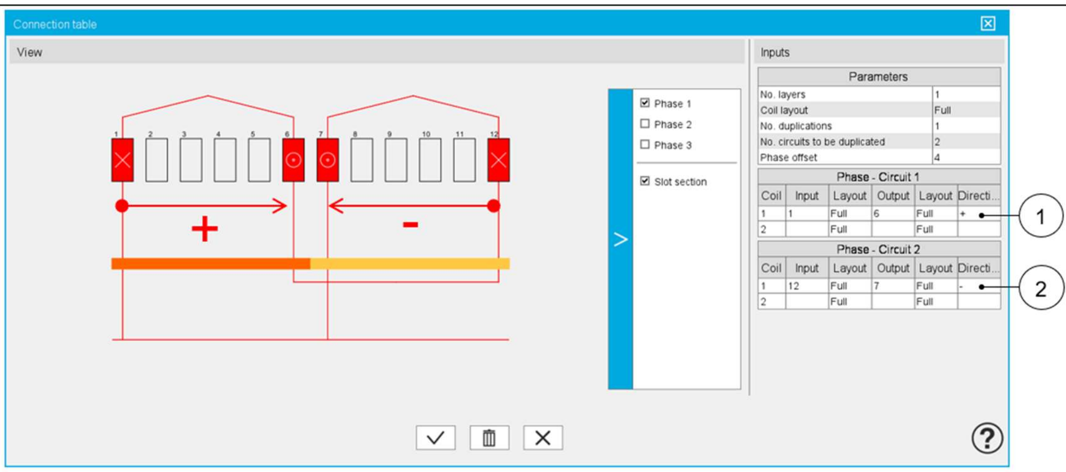
1	Selection of the number of layers. The solutions depend on the number of slots, the number of poles and the number of phases. Example: With 12 slots,10 poles and 3 phases, only one solution is proposed: 1 layer. The three possible cases are illustrated in the Easy mode section.
2	Definition of the coil layout i.e. how the coil sections are distributed into the slot. The three possible choices are: • Full = At least one coil into one slot • Superimposed = At least two superimposed coils into one slot • Adjacent = At least two adjacent coils into one slot The solutions depend on the number of phases, the number of slots and the number of poles. Example 1: With 12 slots, 10 poles and 3 phases, two solutions are proposed: superimposed or adjacent. Note that in that case, only toothed winding is relevant. This corresponds to an adjacent coil layout. Example 2: With 48 slots, 8 poles and 3 phases, one solution is imposed: Full.
3	Definition of the number of duplications. This number is computed and proposed to the user. It depends on the number of slots and the number of poles. When the winding architecture to build is cut into several identical parts, the corresponding possible number of duplications are proposed (a short list). By selecting the number of duplications, the user must define only 1/n of the connection table.
4	Number of circuits to be duplicated represent the number of elementary circuits to be defined inside each sector to be duplicated. In this example 2 circuits are defined in the represented sector. This is why, there are 2 connection tables to be filled in. One for each circuit: Phase 1 – Circuit 1 and Phase 1 – Circuit 2
5	Phase offset – See explanation and illustration below.
6	The connection table(s) must be filled in. 1 or 2 according to the number of circuits to be represented inside the considered elementary sector. • Indication of the slot number which contains the input end of the coil. • Define the coil layout in the slot. • Indication of the slot number which contains the output end of the coil. • Define the coil layout in the slot. Then, another line is proposed to describe the next coil.

2) Phase offset parameter



Building the winding architecture – Filling of the connection table – Phase offset	
1	Definition of the phase offset = number of slot pitch between each phase.
2	Make the phase visible or not. **Note**: All the phases are identical. Phases 2 and 3 are identical to Phase 1 and is displayed in the winding by considering the phase offset.

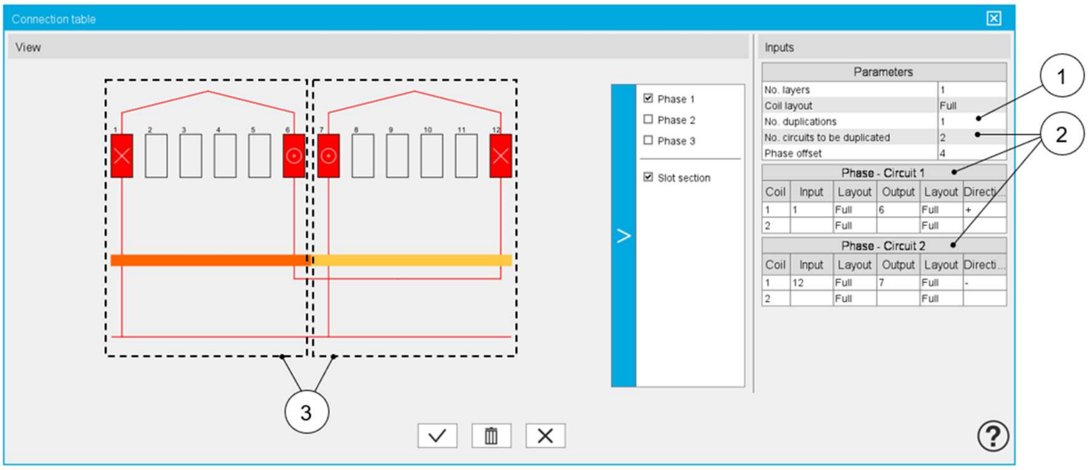
3) Winding direction for coils



Orient the coils when defining the phase circuits	
1	Definition of a positive orientation of coil i.e., in the clockwise direction from the connection size (=ascending order of slot numbers)
2	Definition of a negative orientation of coil i.e., in the counterclockwise direction from the connection size (=descending order of slot numbers)

4) Additional information

The real distribution of the parallel paths in the winding is taken into account for performing the tests. It is why one need to know how the parallel paths are distributed. To do that, in the expert mode, to define the connection table, the user can define the number of circuits to be duplicated and for that, he must fill in a connection table for each elementary parallel path.

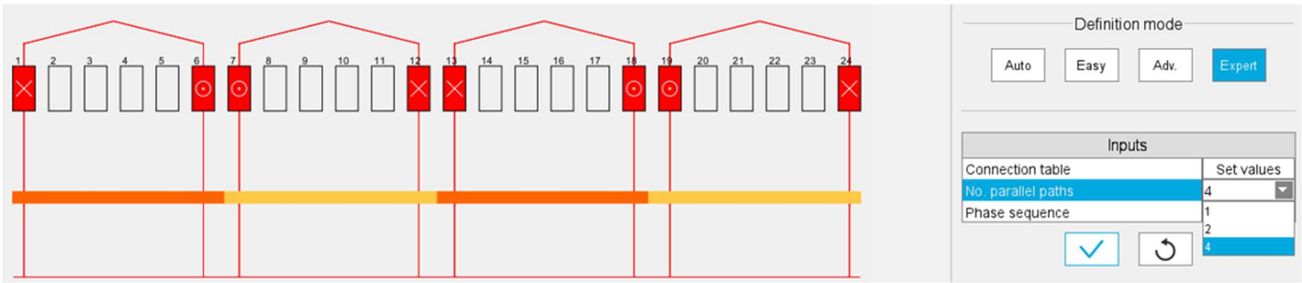


Dialog box for defining the connection table while using the expert mode

1	Number of duplications. See the definition in table above.
2	Number of circuits to be duplicated. See the definition in table above.
3	Representation of the two circuits inside the considered sector.

Then, the list of possible number of parallel paths « No. parallel paths » adapts itself in function to the number of duplications « No. duplications » and the number of circuits to be duplicated « No. circuits to be duplicated ».

Here is the resulting layout of the winding architecture below. There are always 4 possible parallel paths. These circuits can be well connected.



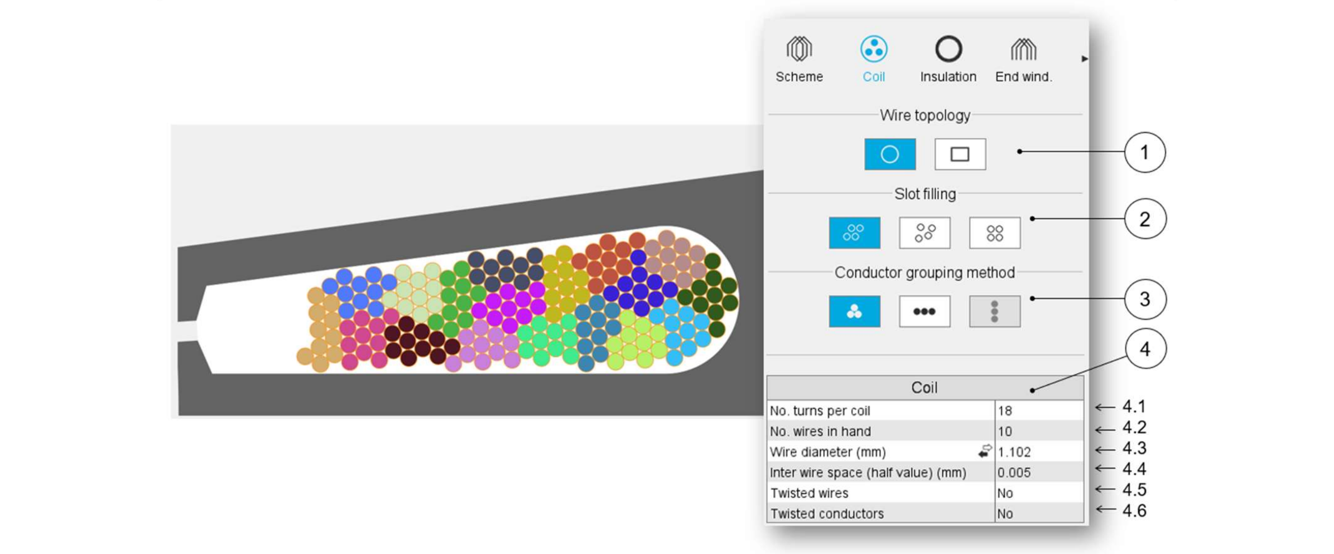
Layout of the resulting winding architecture

Warning:
Concerning, the motors built with a previous version (before 2022.2) and for which the winding was initially defined with the expert mode, when they will open with the current version the user input « No. circuits to be duplicated » will be set automatically to 1 and only one parallel circuit is considered.

Important note: This modification is a problem for motors the number of parallel paths « No. parallel paths » of which is greater to the number of duplications « No. duplications. »
In that case, one has decided to modify the value of the « No. parallel paths » to make it take the value of the « No. duplications ».
Important note: This is done without any warning given to the user

2.3 Coil

2.3.1 Overview – Case of circular wires



Definition of the coil – Case of Circular wires	
1	Definition of the wire topology, Circular or Rectangular
2	Choice of the method to fill the slot: Three ways are allowed to fill the slot: Orthocyclic, Random, Layer. See below illustrations.
3	Choice of method to group the elementary wires. Three ways allow to fill the slot: Grouped, Horizontal, Vertical. See below illustrations.
4	Description of the coil and dimensions of elementary wires + twist options.
4.1	Number of turns per coil
4.2	Number of wires in parallel in a conductor (per turn) i.e. number of wires in parallel in each conductor.
4.3	Wire diameter (without insulation), for circular wire (1)
4.4	Minimum distance between insulated wires to be considered for modelling inside the Flux® 2D environment. When there is no wire insulation, Inter-wire space represents the minimum distance between the bar wires (2).
4.5	The wires can be twisted inside the conductor.
4.6	The conductors can be twisted inside the slot.

Note: 1 - Different ways are available to choose the wire diameter:

- Directly entering the value of the wire diameter (without insulation)
- Choose the diameter from the American Wire Gauge table in which available wire diameters are listed (without insulation)
- Choose the diameter from the Metric Wire Gauge table in which available wire diameters are listed (without insulation)

Note: 2 - Illustration of inter-wire space
This value is considered in Motor factory for computing the filling factor, and while exporting a model into Flux® environment (EXPORT area) for building the corresponding finite element model.

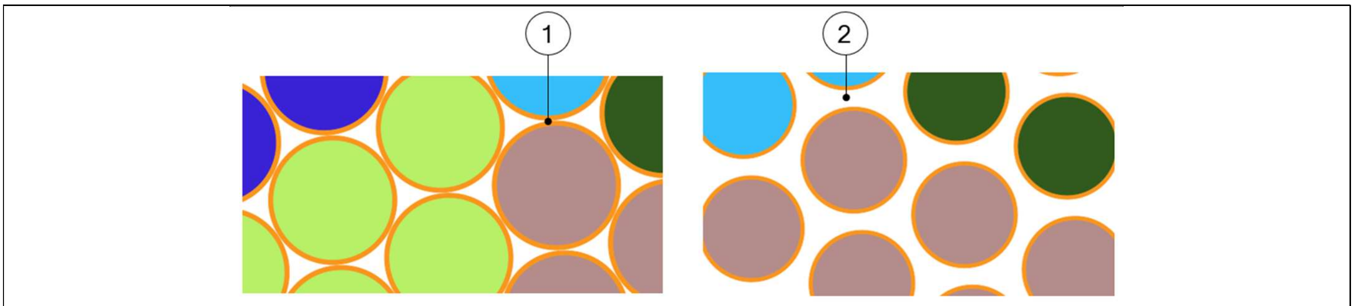
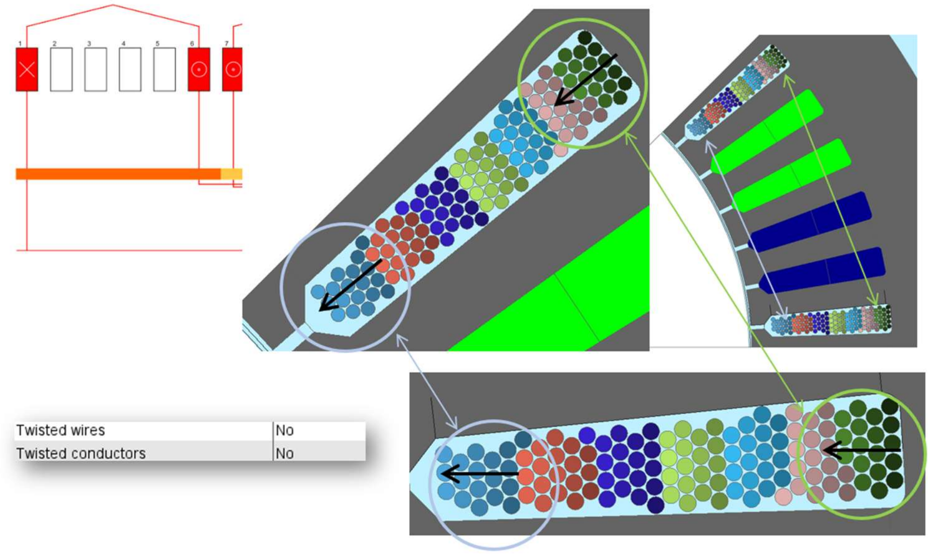
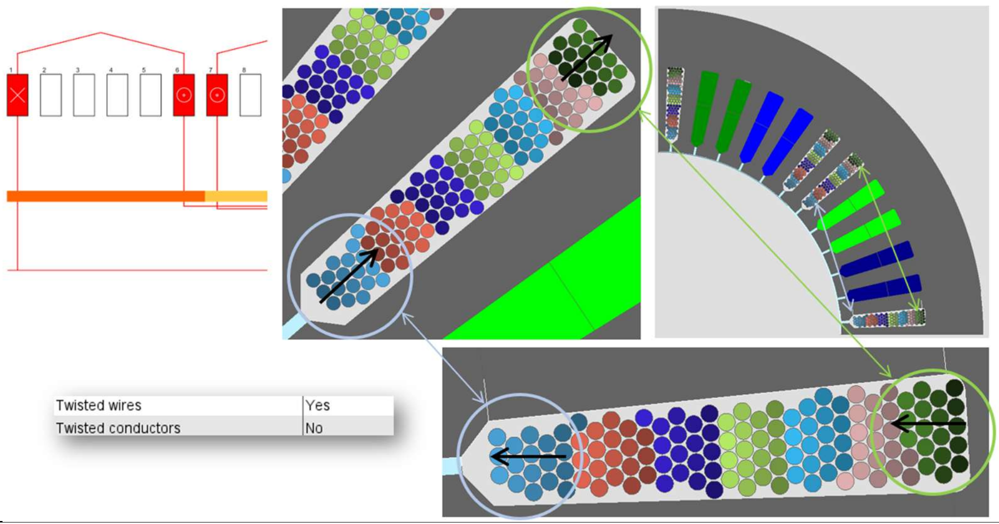


Illustration of inter-wire space	
1	Default value for inter-wire space and the corresponding pictorial display.
2	Impact of a higher value for inter-wire space

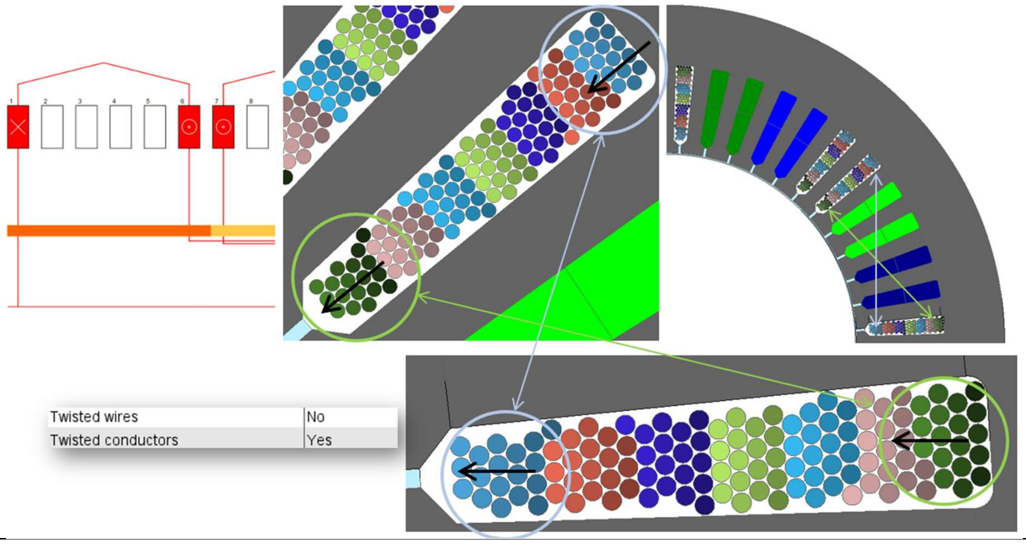
Note: 3 - Twisted conductors and wires
While defining the coil in the design / Winding area, it is possible to twist the wires inside the conductors between the forward and return sections of the coil. It is also possible to twist the conductors between the forward and return sections of the coil.
It is possible to twist both the wires inside the coil and the conductors between the forward and return sections of the coil.
The four illustrations of what it is possible to do are presented below.



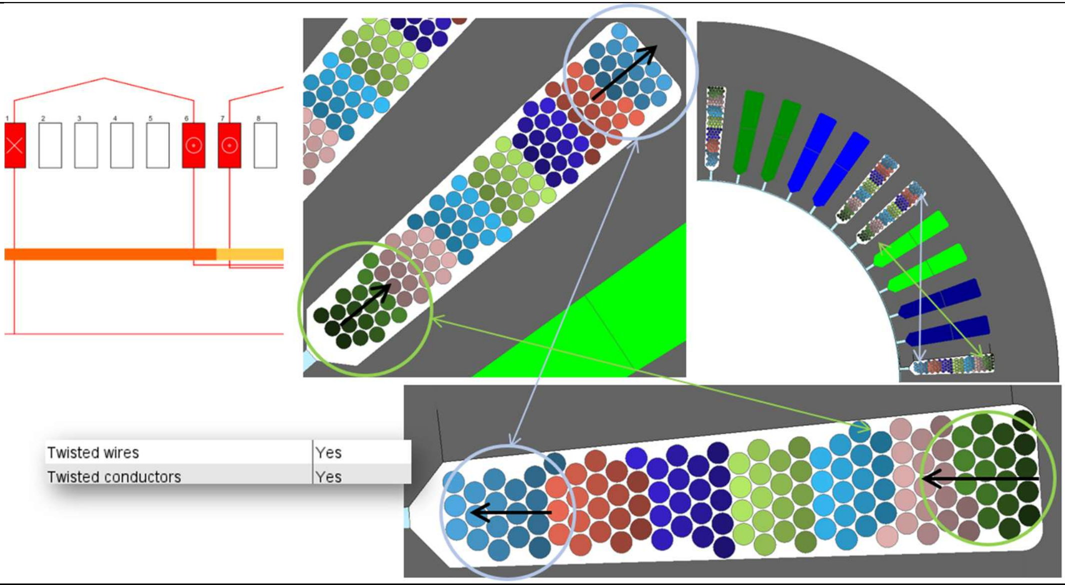
Neither the wires nor the conductors are twisted



The wires are twisted inside the conductors.
The direction of the gradated conductor color indicates the orientation of the twist.

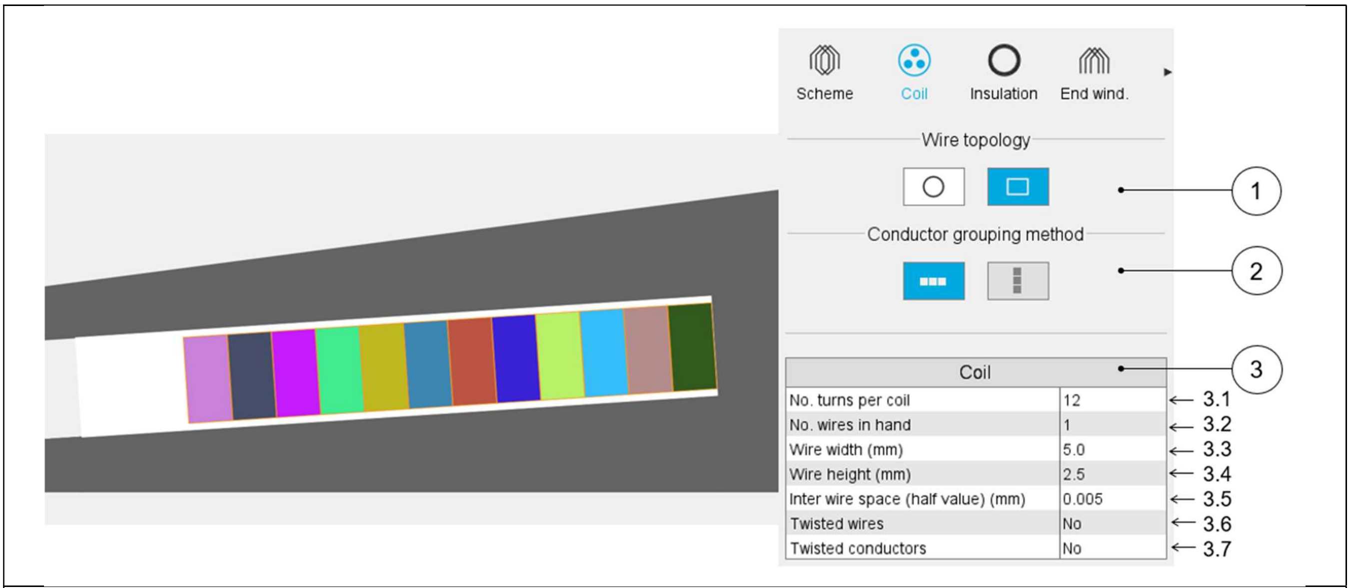


The conductors are twisted between the forward and return sections of the coil.
The conductor colors indicate the position of conductors



The wires are twisted inside the conductors and
the conductors are twisted between the forward and return sections of the coil.

2.3.2 Overview – Case of rectangular wires

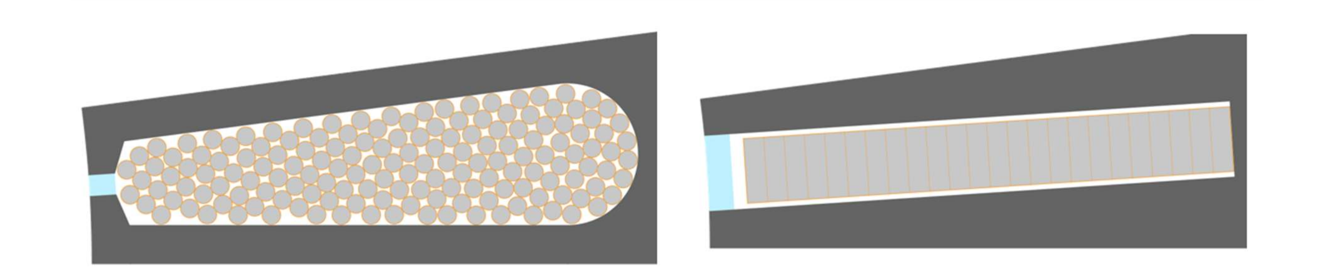


Definition of the coil – Case of rectangular wires	
1	Definition of the wire topology, Circular or Rectangular
2	Choice of the method to group the elementary wires. Two ways allow to fill the slot: Horizontal, Vertical. See next sections which illustrate the grouping methods.
3	Description of the coil and dimensions of elementary wires + twist options.
3.1	Number of turns per coil
3.2	Number of wires in parallel in a conductor (per turn) i.e. number of wires in parallel in each conductor.
3.3	Wire width (without insulation), for rectangular shape type wire.
3.4	Wire height (without insulation), for rectangular shape type wire.
3.5	Minimum distance between insulated wires to be considered for modelling inside the Flux® 2D environment. When there is no wire insulation, Inter-wire space represents the minimum distance between the bar wires.
3.6	The wires can be twisted inside the conductor.
3.7	The conductors can be twisted inside the slot.

Explanation about the different ways to choose the wire diameter, the inter-wire space and the twisted conductors and wires are presented in the section dedicated to the circular wires.

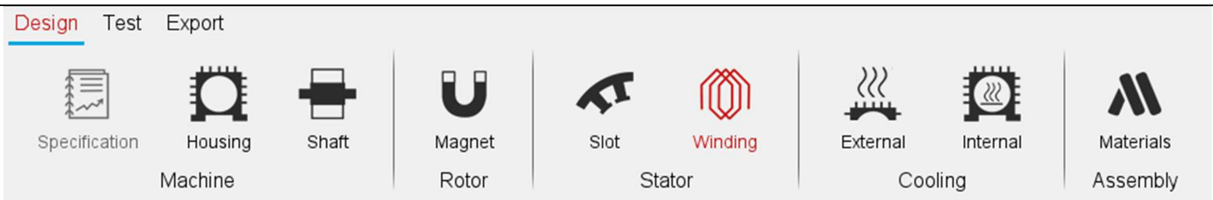
2.3.3 Relevance of the slot filling

When the number of wires are higher than allowed by the free space of the slot, the wires are grayed. This is to inform the user that the number of wires must be decreased.
In that case, the design of the winding is not possible; the machine cannot be built or tested.



Grayed circular or rectangular shape type wire

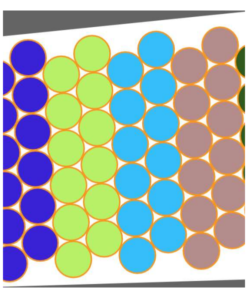
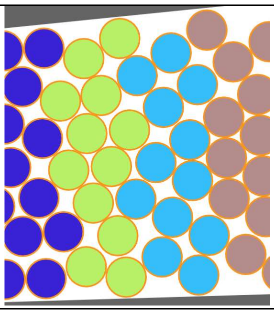
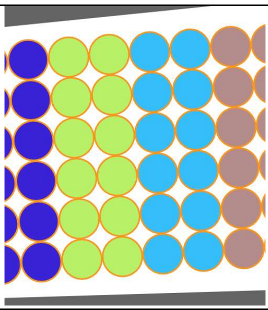
Motor Factory Design environment icon and winding icon in the Stator section are colored in red. This means that a design fault exists, and must be corrected in the winding section of the design environment.



Motor Factory Design environment Icon and the winding icon in the Stator section are colored in red.
= a design fault must be corrected

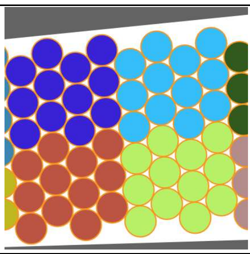
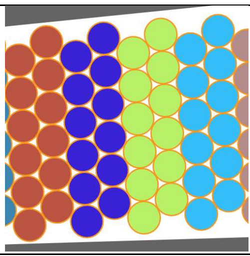
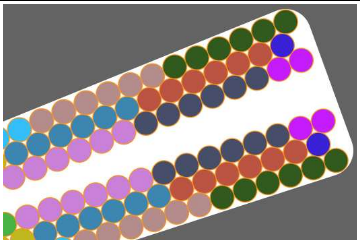
The tests cannot be performed; the tooltip message indicates that the slot filling is not valid, and that the user must modify the slot filling parameters to unlock the test.
At the same time, a warning message indicates that there is not enough space for the specified number of wires. The allowed number of wires are mentioned in comparison with the targeted ones.

2.3.4 Slot filling illustrations – Circular shape type wire

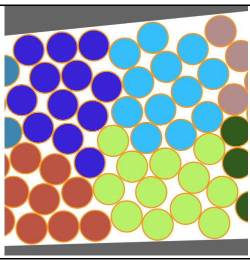
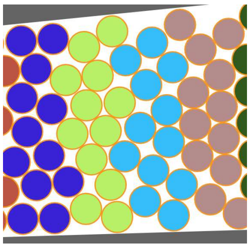
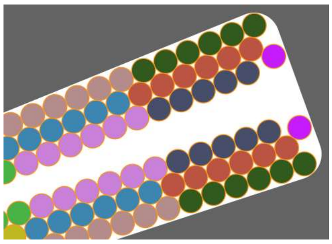
		
Orthocyclic slot filling	Random slot filling	Layer slot filling

2.3.5 Conductor grouping method illustrations - Circular shape type wire

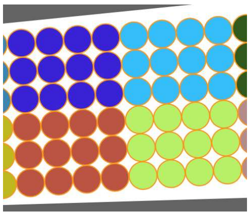
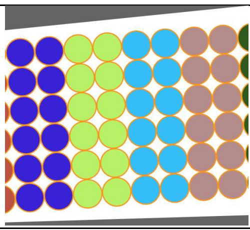
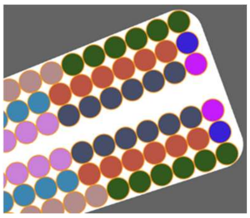
2.3.5.1 Case 1 – With an Orthocyclic slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

2.3.5.2 Case 2 – With a random slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

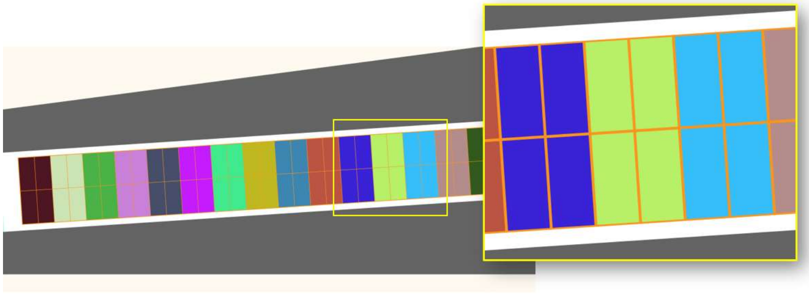
2.3.5.3 Case 3 – With a layer slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

(1) Vertical filling is only available for tooth windings (i.e. when the coil pitch = 1)

2.3.6 Conductor grouping method illustrations - Rectangular shape type wire

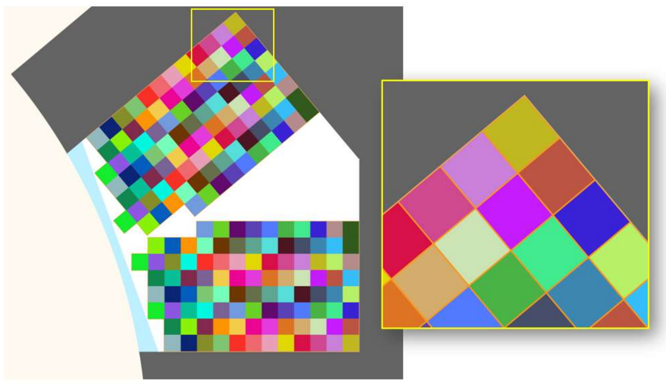
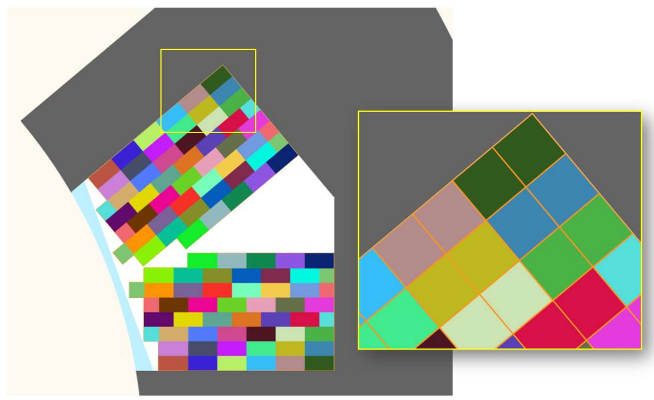
Example 1



Horizontal filling

Note: Vertical filling is only available for tooth windings (i.e. when the coil pitch = 1)

Example 2 with a tooth winding (i.e. the coil pitch = 1)

	
Horizontal filling	Vertical filling (1)

(1) Vertical filling is only available for tooth windings (i.e. when the coil pitch = 1)

2.4 Insulation

2.4.1 Reminder – Definition and terminology

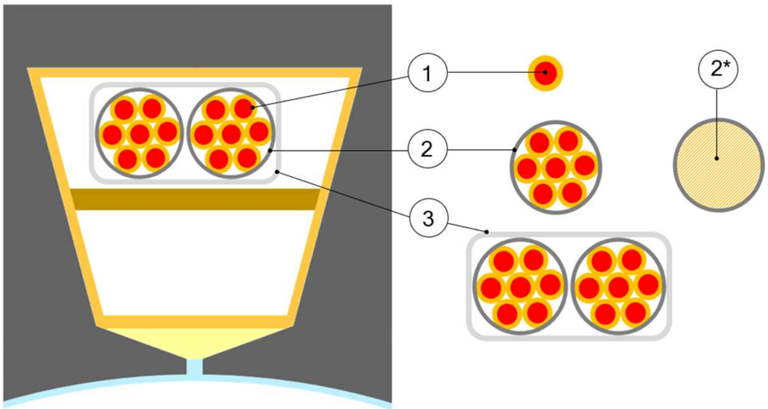


Illustration of the slot composition

1	Wire (also called strand).
2	Conductor, that also corresponds to a turn section (one conductor = one turn). A conductor is composed with one or several wires in parallel (wires in hand).
2*	The hatched area corresponds to the conductor’s useful area. Area which includes: the wires + insulation + free space. This is not the conductive area.
3	Coil, which is an assembly of several conductors (i.e. several turns per coil).

2.4.2 Circular shape type wire

Here are all the available insulation types.

Label	Tooltip, note, formula
Wire	Insulation thickness of the wire
Conductor	Insulation thickness of the conductor. Available only for rectangular shape type wire. See below illustration.
Coil	Insulation thickness of the coil. Available only for rectangular shape type wire. See below illustration.
Liner	Insulation thickness of the liner
Phase separator	Insulation thickness of the phase separator
Impregnation	Insulation spread inside the slot
Impregnation goodness	Quality of impregnation (percentage of winding impregnation)

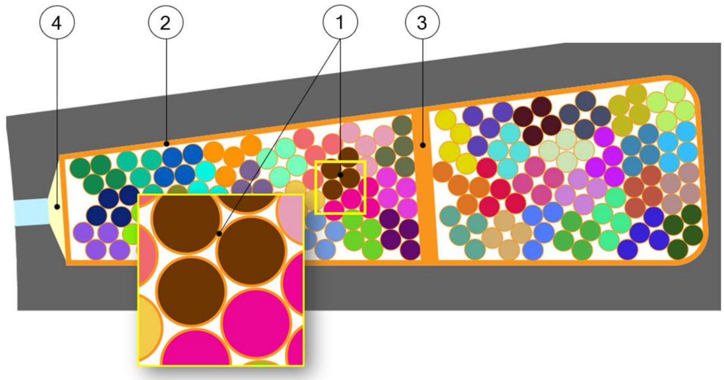


Illustration of winding insulation for circular shape type wire

1	Insulation thickness of the wire
2	Insulation thickness of the liner
3	Insulation thickness of the phase separator
4	Wedge to close the slot and maintain the winding inside. It is a part of the slot insulation. However, when needed, the wedge must be defined in the slot topology configuration and not in the insulation settings of the winding area.

2.4.3 Rectangular shape type wire

Here are all the available insulation types.

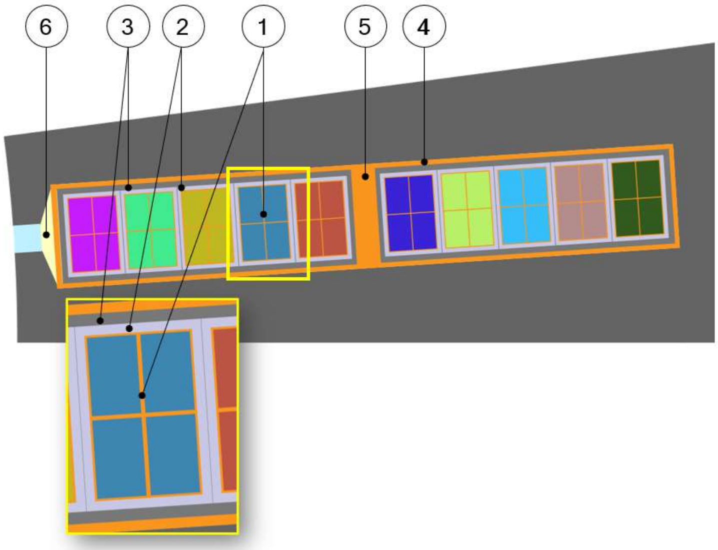


Illustration of winding insulation for rectangular shape type wire	
1	Insulation thickness of the wire
2	Insulation of conductors. This is available only for rectangular shape type wire when the conductor (i.e. the elementary group of wires in hand) has a rectangular outer shape.
3	Insulation of coils. This is available only for rectangular shape type wire when the coil (i.e. the group of turns inside a layer) has a rectangular outer shape.
4	Insulation thickness of the liner
5	Insulation thickness of the phase separator
6	Wedge to close the slot and maintain the winding inside. It is a part of the slot insulation. However, when needed, the wedge must be defined in the slot topology configuration and not in the insulation settings of the winding area.

2.4.4 Impregnation

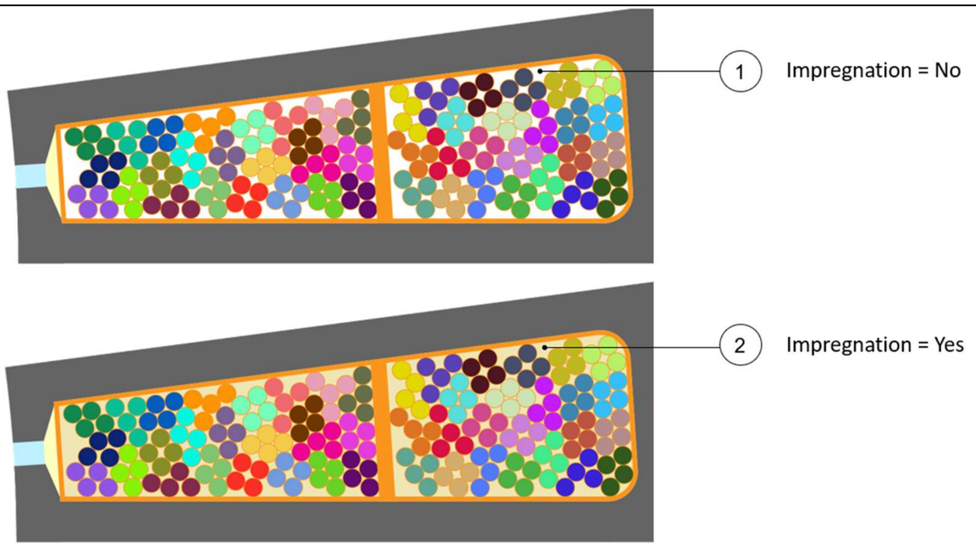


Illustration of winding impregnation in slot

1	Winding without impregnation. The surface of the slot's free area is white.
2	Winding with impregnation. The free area of the slot is colored (light yellow). The impregnation goodness is defined by indicating the ratio between the volumes of impregnation material and air bubbles to be considered.

2.5 End winding

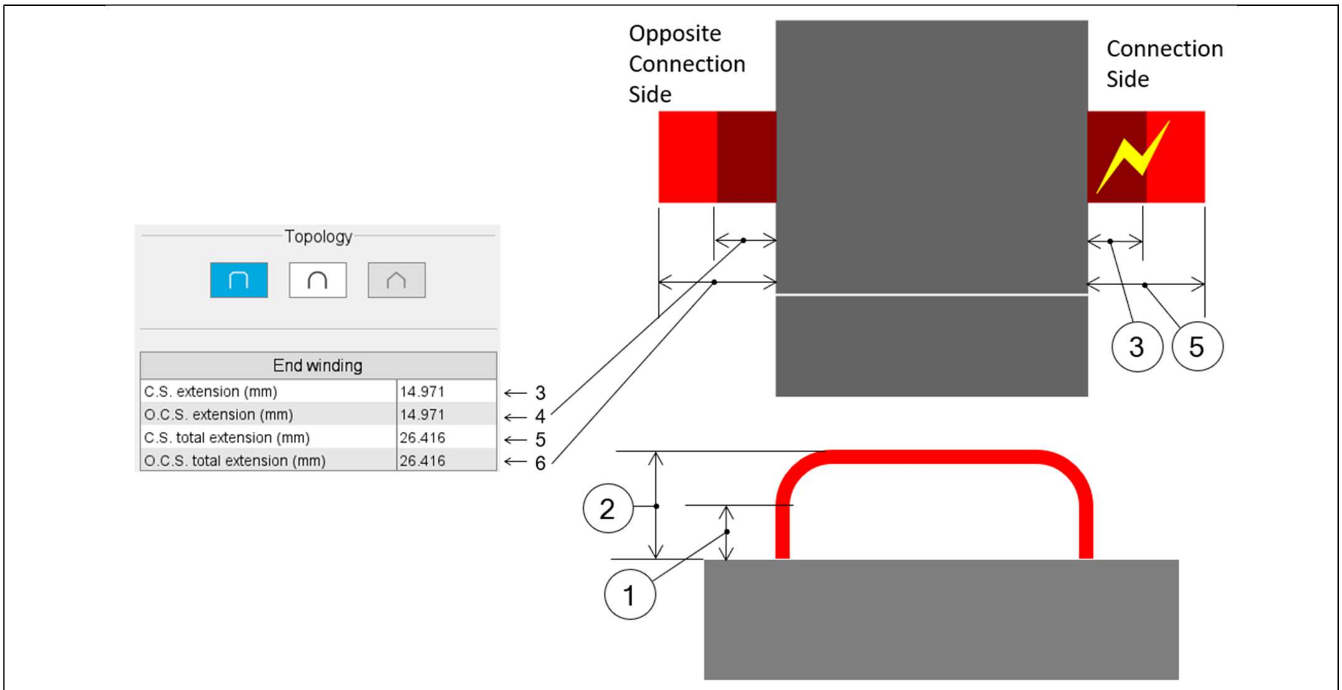
2.5.1 Overview - definitions

This part characterizes the end-winding and the resulting conductor dimensions.
For additional information refer to the sections dedicated to the coil and conductor settings and End-winding topology.

Label	Tooltip, note, formula
End-winding topology	End-winding topology: U-shape, C-shape or Y-shape.
C.S. total extension	Connection side total extension.
C.S. straight extension	Connection side straight extension
Axial overall length	Axial overall length. Length between the two extremities of the winding i.e. between connection side and opposite connection side.
O.C.S. total extension	Opposite connection side total extension.
O.C.S. straight extension	Opposite connection side straight extension.
Total conductor length	Total conductor length.
Mean turn length	Mean turn length.
Coil connection length	Additional length corresponding to the connections between coils.

2.5.2 U-Shape topology

Topology available for all the 3 winding architectures

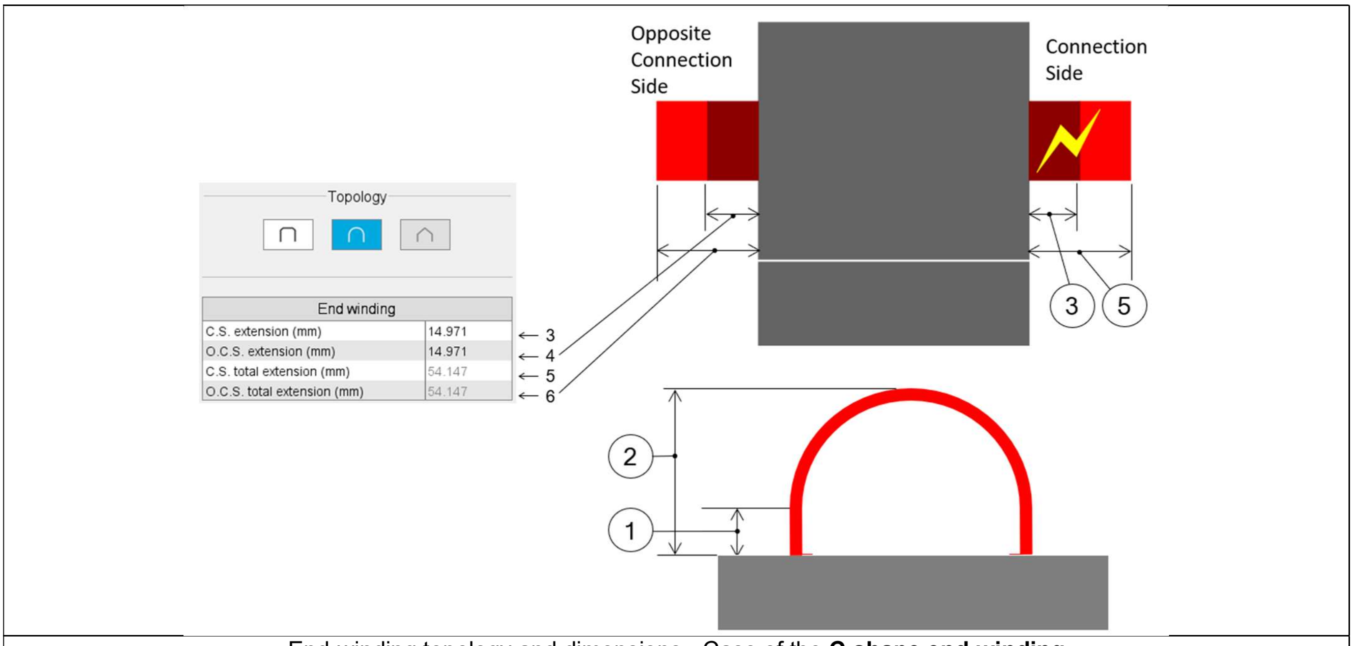


End-winding topology and dimensions - Case of the **U-shape end-winding**

1	Straight extension of the U-Shape end-winding topology = User input parameter.
2	Total extension of the U-Shape end-winding topology = User input parameter.
3	Definition of the connection side straight extension (ref. 3).
4	Definition of the opposite connection straight extension (ref. 4).
5	Definition of the connection side total extension (ref. 5).
6	Definition of the opposite connection side total extension (ref. 6).

2.5.3 C shape topology

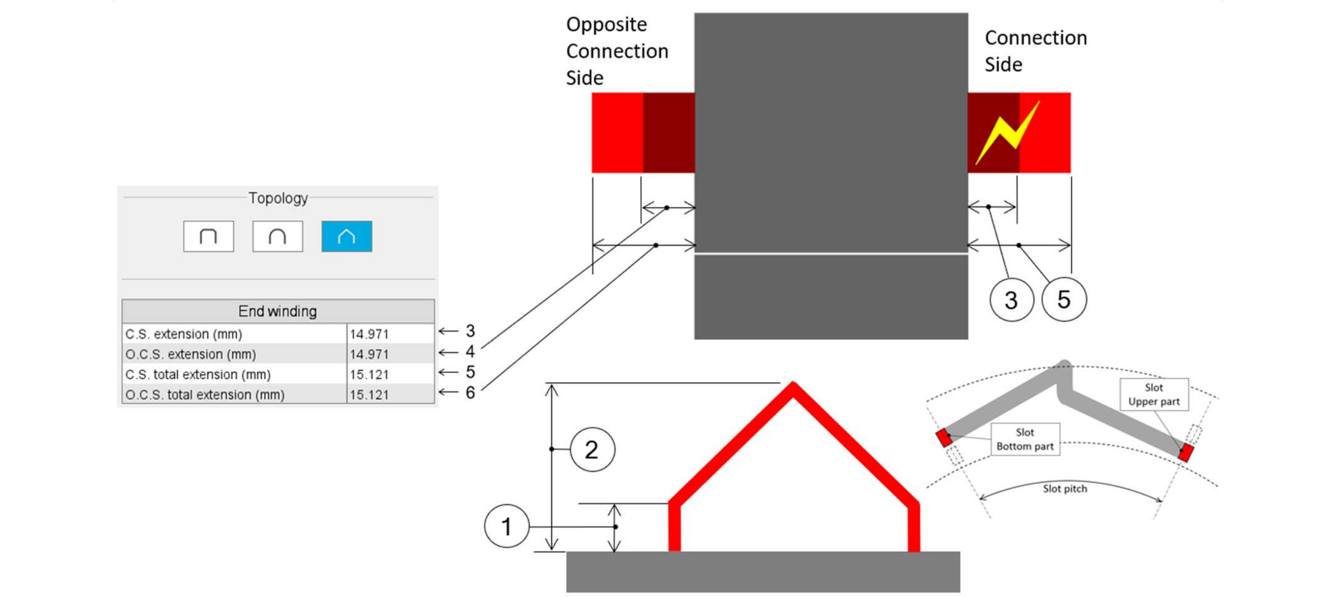
Topologies available for all winding architecture



End-winding topology and dimensions - Case of the **C-shape end-winding**	
1	Straight extension of the C-Shape end-winding topology = User input parameter.
2	Total extension of the C-Shape end-winding topology = Computation result deduced from topology characteristics.
3	Definition of the connection side straight extension = User input (ref. 3).
4	Definition of the opposite connection straight extension = User input (ref. 4).
5	Definition of the connection side total extension = Deduced result (ref. 5).
6	Definition of the opposite connection side total extension = Deduced result (ref. 6).

2.5.4 Y shape topology

This topology is available only with two layers and superimposed coil layout.

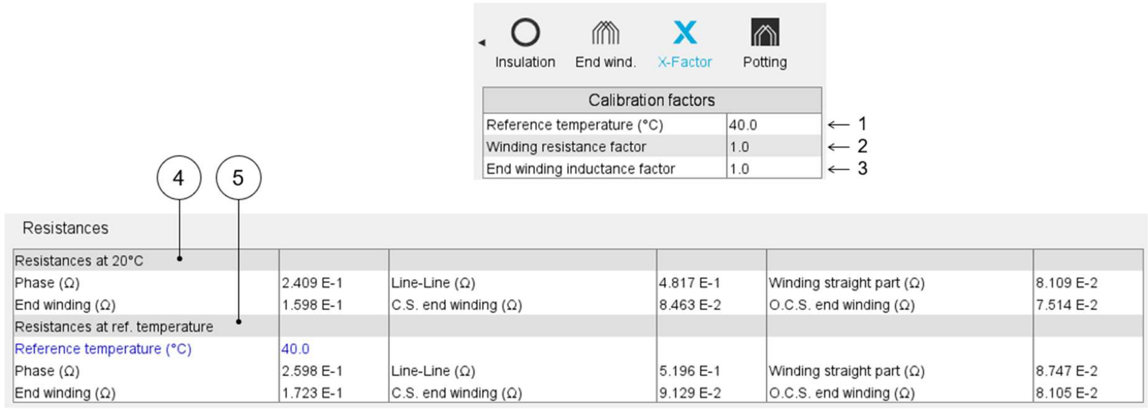


End-winding topology and dimensions - Case of the **Y-shape end-winding**

1	Straight extension of the Y-Shape end-winding topology = User input parameter.
2	Total extension of the Y-Shape end-winding topology = User input parameter.
3	Definition of the connection side straight extension (ref. 3).
4	Definition of the opposite connection straight extension (ref. 4).
5	Definition of the connection side total extension (ref. 5).
6	Definition of the opposite connection side total extension (ref. 6).

2.6 X-Factor

2.6.1 Illustrations



Building the winding – X-Factor = Calibration factors

1	The reference temperature: First, resistance values are computed by considering a temperature equal to 20°C (4). However, the users can also define their own reference temperature to compute the corresponding phase resistance and Line-Line resistance values. By default the reference temperature is equal to 20°C. In our example this value is set to 40°C.
2	Setting of the “Resistance factor”. It allows adjusting computation result of resistance. Thus, the resulting phase resistance value is considered.
3	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.
4	Resistance values for a fix reference temperature equal to 20°C.
5	Resistance values for the reference temperature chosen by the user.

Note: the reference temperature which is considered in the winding design area doesn’t impact the thermal conditions considered in the framework of tests.

Warning: End winding resistance can be negative with low value of X-Factors.
Here are a few explanations for this issue:
This issue has been introduced while considering the solid conductors inside the slot. Since the solid conductors are considered, the corresponding resistance (in the straight part of the machine) is deduced from the material properties and the size of the wires.

With X-factor=1, we have $(Rphase\ 0) = (Rstraight\ 0) + (R\ end\ winding\ 0)$

- $Rphase\ 0$ is the initial value of the phase resistance (with X-Factor = 1)
- $RStraight\ 0$ is the initial value of the phase resistance in the straight part of the machine (with X-Factor = 1)
- $R\ end\ winding\ 0$ is the initial value of the phase resistance in the straight part of the machine (with X-Factor = 1)

With X-factor≠1, we have $(Rphase\ 1) = (Rstraight\ 1) + (R\ end\ winding\ 1)$

- $Rphase\ 1$ is the initial value of the phase resistance (with X-Factor ≠1)
- $RStraight\ 1$ is the initial value of the phase resistance in the straight part of the machine (with X-Factor ≠1)
- $R\ end\ winding\ 1$ is the initial value of the phase resistance in the straight part of the machine (with X-Factor ≠1)

The target is to get the following results:

$$(Rphase\ 1) = XFactor \times (Rstraight\ 0)$$

With
$(Rstraight\ 1) = (Rstraight\ 0)$

This leads to the value for the end winding resistance:

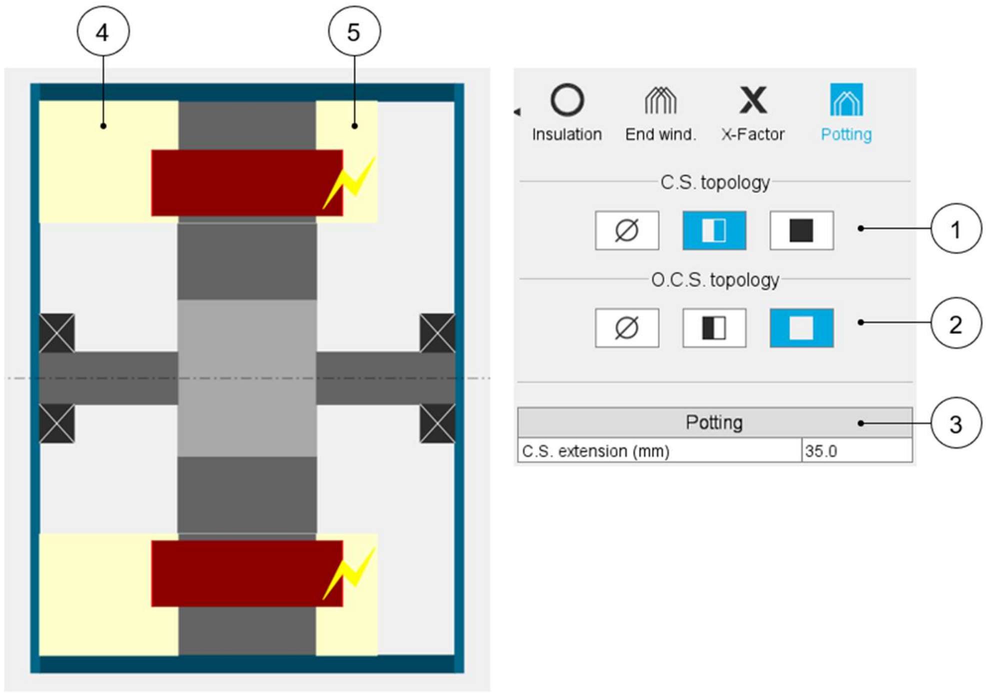
$$(R\ end\ winding\ 1) = XFactor \times (Rstraight\ 0 + R\ end\ winding\ 0) - (Rstraight\ 0)$$
$$(R\ end\ winding\ 1) = Rstraight\ 0 \times (XFactor - 1) + XFactor \times (R\ end\ winding\ 0)$$

When X-Factor is very low, the end winding resistance can be negative.
We will reconsider how to apply the calibration factor to the winding resistance. Perhaps this will lead to applying the X-Factor only to the end winding and the winding connections not to then straight part.
Note: This problem doesn't impact the phase resistance value, nor the resulting computations, like the total Joule losses in the winding.

2.7 Potting

2.7.1 Overview - Definitions

“Potting” section is available only when the housing is defined with a frame (circular or square shape).



Definition of the topology and dimensions of the potting around the end-winding	
1	Button to define a potting with only radial contact (at connection side in this example)
2	Button to define a potting with radial and axial contacts (at opposite connection side in this example).
3	Dimensions for defining the selected potting.
4	Extension of potting with both contact axial and radial.
5	Extension of potting with radial contact only.

3 HAIRPIN WINDING

3.1 Overview

3.1.1 Differences with classical winding

The design of Hairpin winding type meets some limitations compared to the classical winding:

- Only three-phase winding is considered.
- Only integer number of slots per pole and per phase are allowed (fractional numbers are forbidden)
- A coil corresponds to one hairpin and not to an association of hairpins and back connections in serial.
- The hairpin which are associated in serial (thanks to back connections) are called parallel path or elementary coil.
- The number of turns in series per phase is defined by the number of conductors per layer, the number of layers and the number of parallel paths.
- Number of wires in hand is imposed to 1.
- Wire shape can be rectangular only.
- Insulation for conductors and coils are not available (please refer to the definition of coils and conductors)
- End winding shape can be Y shape only.
- New results of quality criteria dedicated to hairpin winding are available:
  - Current balance for parallel paths
  - Voltage drops between conductors.
- X-factor section gives an access to the inputs of the results “Conductor voltage drop.”

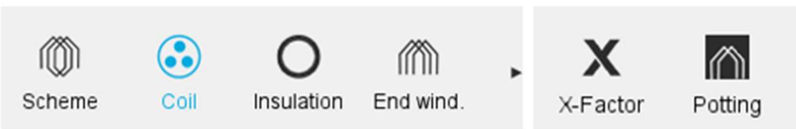
All these points are described in the following sections.

3.1.2 Design

A scrolling selection bar helps to choose the section in which one can define the winding settings.
Here are the sections available to design the winding step by step:

- “Scheme” to build the winding architecture.
- “Coil” to set how the coil is defined and to see how the slots are filled.
- “Insulation” to define all the winding insulations.
- “End winding” to define the topology and dimensions of the end-windings.
- “X-Factor” to adjust phase resistance and end-winding inductance.
- “Potting” to define the topology and dimensions of the potting around the end-winding.

Note: “Potting” section is available only when the housing is defined with a frame (circular or square shape).

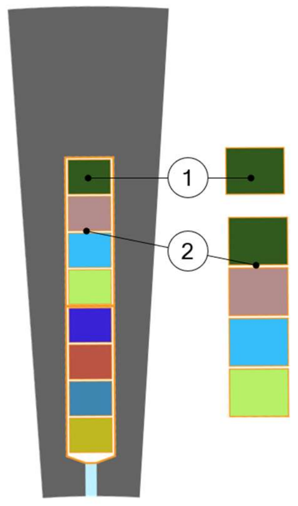


Sections to design the winding step by step

Note: In the software winding datasheet, the parameters written in blue correspond to user input parameters and the parameters written in black correspond to data resulting from computations.

3.1.3 Terminology

Refer to the section “Terminology – Illustration” dedicated to classical and hairpin winding technology.



Slot composition	
1	Conductor (also called bundle). That also corresponds to a turn section (one conductor = one turn). For hairpin winding type, a conductor is composed with only one wire (one wire in hand).
2	A coil which is an assembly of several conductors (i.e. several turns per coil).

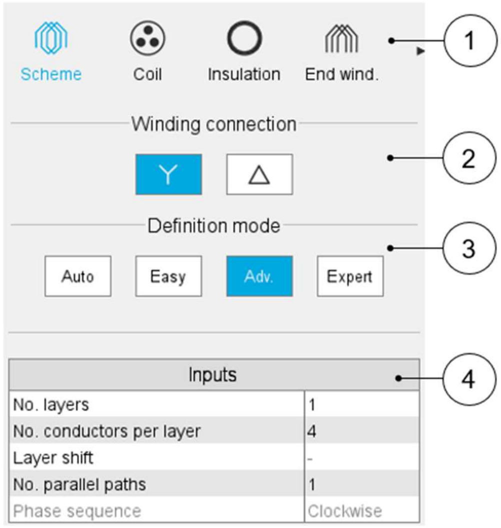
3.1.4 Classical winding outputs

Please refer to the section “Winding / Winding outputs” dedicated to classical and hairpin winding technology.

3.2 Scheme

3.2.1 Overview

Here are below the winding scheme user inputs.

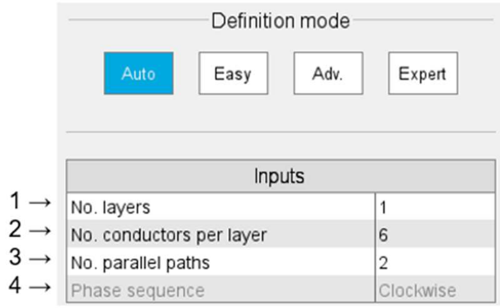


Inputs to define the winding architecture = winding scheme	
1	Sections to design the winding step by step.
2	Winding connection (Y – Wye or Δ - Delta)
3	Winding definition mode: Automatic, Easy, Advanced or Expert. See below section dedicated to the construction of the winding architecture.
4	List of user inputs to define the winding architecture. See the corresponding definition below.

3.2.2 Definition modes

There are four winding definition modes: Automatic, Easy, Advanced or Expert. See below the corresponding illustration.

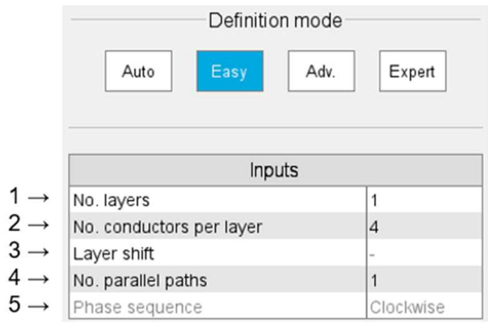
3.2.3 Automatic



Definition mode – **Automatic** mode

1	Number of layers - 1 is the only value available for this mode
2	Number of conductors per layer, must be even and limited to 30. An automatic drop-down list is provided.
3	Number of parallel paths. The possible numbers of parallel paths are automatically computed and proposed to the user, 2 is the maximum proposed value according to the used hairpin pattern. When the user selects a number of parallel paths the connections on the winding scheme are automatically updated.
4	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counter clockwise. The rotation direction is defined when facing the machine on the connection side. The phase sequence is set to clockwise and cannot be modified in the current version (grayed field).

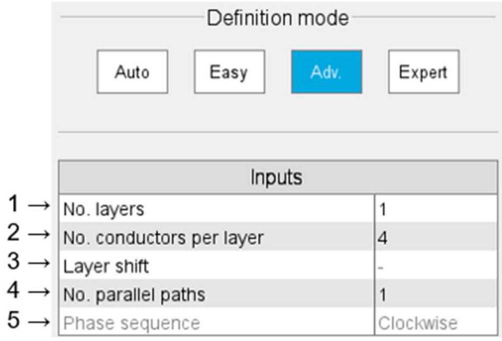
3.2.4 Easy



Definition mode – **Easy** mode

1	Selection of the number of layers. The number of layers are limited to 2. An automatic drop-down list is provided.
2	Number of conductors per layer must be even and limited to 30. An automatic drop-down list is provided.
3	The layer shift is defined by a number of slot pitch. It cannot exceed the number of slots per pole and per phase. (Only available with 2 layers).
4	Number of parallel paths. The possible numbers of parallel paths are automatically computed and proposed to the user, 2 is the maximum value proposed according to the considered hairpin pattern. When the user chooses several parallel paths the connections on the winding scheme are automatically updated.
5	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counter clockwise. The rotation direction is defined when facing the machine on the connection side. The phase sequence is set to clockwise and cannot be modified in the current version (grayed field).

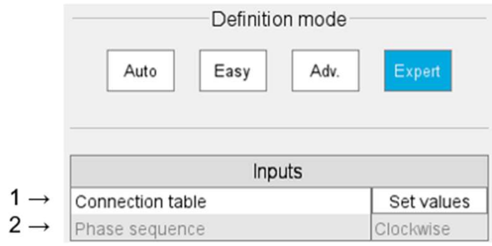
3.2.5 Advanced



Building the winding architecture - **Advanced** mode

1	Selection of the number of layers. The number of layers are limited to 2. An automatic drop-down list is provided.
2	Number of conductors per layer must be even. The user is free to choose the value they want.
3	The layer shift is defined by a number of slot pitch. It cannot exceed the number of slots per pole and per phase. (Only available with 2 layers).
4	Number of parallel paths. The possible numbers of parallel paths are automatically computed and proposed to the user, 2 is the maximum value proposed according to the considered hairpin pattern. When the user chooses several parallel paths the connections on the winding scheme are automatically updated.
5	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counter clockwise. The rotation direction is defined when facing the machine on the connection side. The phase sequence is set to clockwise and cannot be modified in the current version (grayed field).

3.2.6 Expert



Building the winding architecture - **Expert** mode

1	“Set values” means opening the dialog box to fill the connection table. See illustration below.
2	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counter clockwise. The rotation direction is defined when facing the machine on the connection side. The phase sequence is set to clockwise and cannot be modified in the current version (grayed field).

3.2.7 Connection table

3.2.7.1 Presentation

Building the winding architecture – Filling of the connection table	
1	Dialog box to define a connection table with expert mode.
2	Field to upload a connection table defined into a *.xlsx file.
3	Box to manually fill a connection table or modify an uploaded one from a *.xlsx file.
4	Dynamic view of the hairpin winding updated in real time in function of the filling status of the connection table.
5	Selection of the number of layers. Number of layers are limited to 2
6	Number of conductors per layer (This value must be even)
7	Number of slots per pole and per phase to set. No more than 2 times the number of slots per pole and per phase
8	Area to customize the view. For each elementary coil set in parallel (A, B, C…): • Conductor number or current direction can be plotted • Hairpin or/and back-end connections can be displayed or not according to the selected elementary coils in the dialogue box

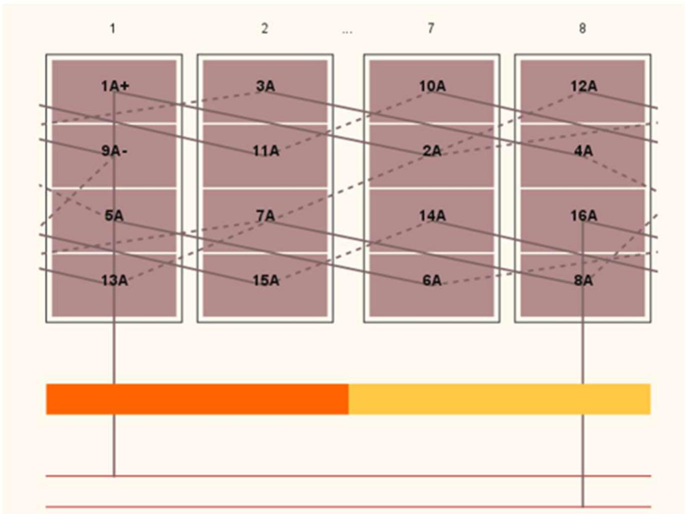
3.2.7.2 Main rules to fill the connection table

Here are the main rules to fill the connection table or to define a *.xlsx equivalent file:

- Define the number of layers, the number of conductors per layer and the number of slot/pole/phase according to the expected hairpin winding configuration
- Each parallel path (also called elementary coil) is characterized by a letter (A, B, C…, AA, AB,…)
- The parallel path A must begin by 1A+ or 1A-. 1 corresponds to the first conductor number. Each added conductor increment the conductor number by one.
  - "+" or "-" correspond respectively to "clockwise" or "counterclockwise" direction of rotation of a parallel path (or part of a parallel path). Only the first conductor of a hairpin (odd number) can define the direction of rotation.
  - The rotation direction is defined when facing the machine on the connection side.

3.2.7.3 Example

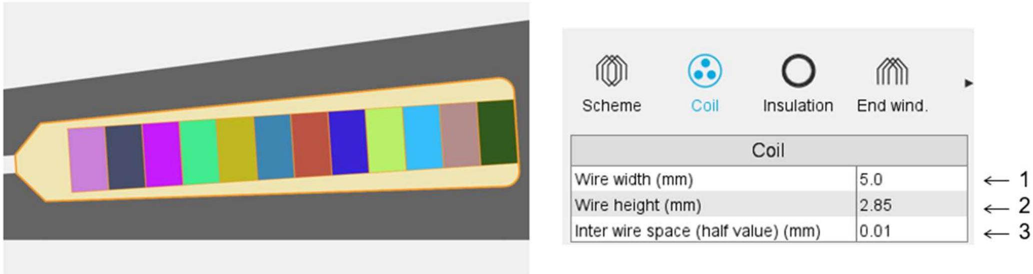
How to define a parallel path composed of 16 conductors in which the first 8 rotates in the clockwise way (conductor 1 -> 8) and the other 8 rotates in the counterclockwise way (conductor 9 → 16)?
The first conductor of the first 8 conductors must be defined as "1A+" to rotate in the clockwise direction.
Then the first conductor of the last 8 conductors must be defined as "9A-" to rotate in the counterclockwise direction.



How to define parallel paths in the connection table?

3.3 Coil

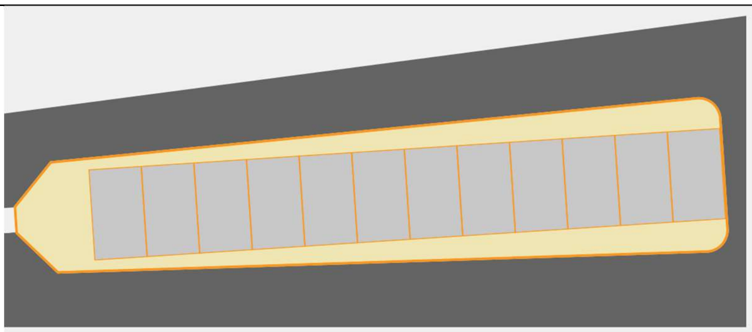
3.3.1 Overview



Definition of the hairpin coil	
1	Wire width (without insulation), for rectangular shape wire.
2	Wire height (without insulation), for rectangular shape wire
3	Minimum distance between wires (with or without insulation) to be considered for modelling inside the Flux® 2D environment. This parameter allows getting a better wire distribution inside the slot.

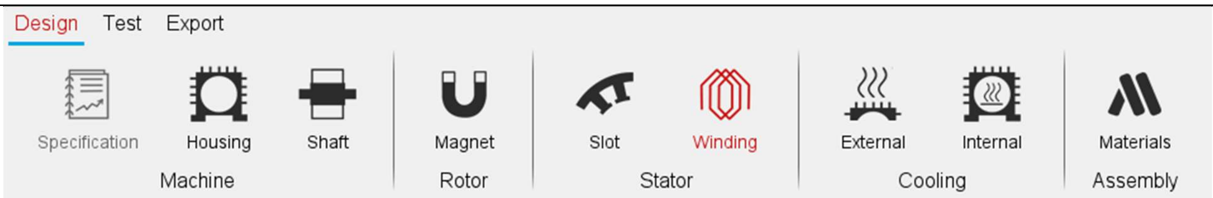
3.3.2 Relevance of the slot filling

When the number of wires (induced by the number of conductors per layer and the number of layers) are higher than allowed by the slot free area, the wires are grayed in the slot filling view. This is to inform the user that the number of wires must be decreased, so, with hairpin technology, the number of conductors per layer.
In that case, the design of the winding is not possible; the machine cannot be built or tested.



Grayed circular or rectangular shape type wire

Motor Factory Design environment button and winding icon in the Stator section are colored in red. This means that there exist a fault in the design, which must be corrected.



Motor Factory Design environment Icon and the winding icon in the Stator section are colored in red.
= a design fault must be corrected

The tests cannot be performed; the tooltip message indicates that the slot filling is not valid, and the user must modify the slot filling parameters to unlock the test.
At the same time, a warning message indicates that there is not enough space for the specified number of wires. The allowed number of wires are mentioned in comparison with the targeted ones.

3.4 Insulation

3.4.1 Overview - Definitions

Here are all the available insulation types.

Label	Tooltip, note, formula
Wire	Insulation thickness of the wire
Liner	Insulation thickness of the liner.
Phase separator	Insulation thickness of the phase separator.
Impregnation	Insulation spread inside the slot.
Impregnation goodness	Quality of impregnation (percentage of winding impregnation).

3.4.2 Illustration

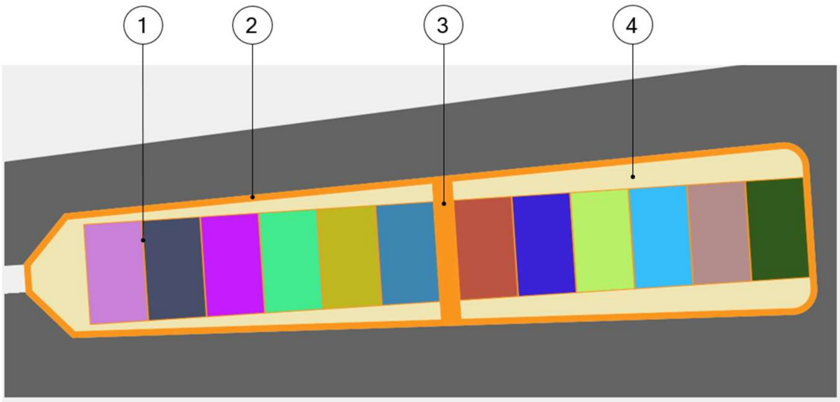


Illustration of winding insulation for rectangular shape type wire

1	Insulation thickness of the wire
2	Insulation thickness of the liner
3	Insulation thickness of the phase separator
4	Presence of impregnation

3.5 End winding

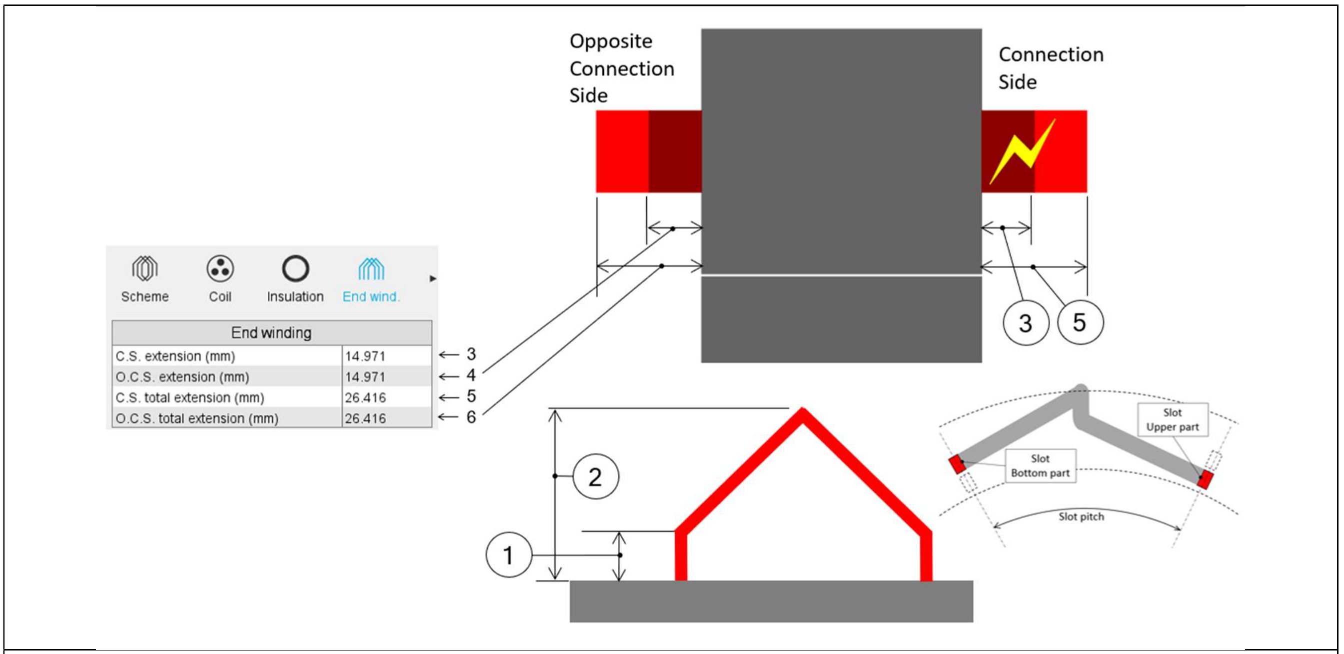
3.5.1 Overview - definitions

This part characterizes the end-winding and the resulting conductor dimensions.
For additional information refer to the sections dedicated to the coil and conductor settings and End-winding topology

Label	**Symbol**	**Tooltip, note, formula**
End-winding topology	*	End-winding topology: Y-shape only
C.S. total extension	*	Connection side total extension.
C.S. straight extension	*	Connection side straight extension
O.C.S. total extension	*	Opposite connection side total extension.
O.C.S. straight extension	*	Opposite connection side straight extension.

Note: One topology is available: Y-shape end-winding.

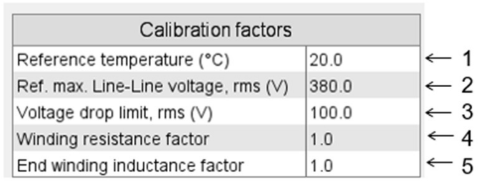
3.5.2 Y-Shape topology



End-winding topology and dimensions - **Y-shape end-winding**	
1	Straight extension of the Y-Shape end-winding topology = User input parameter.
2	Total extension of the Y-Shape end-winding topology = User input parameter.
3	Definition of the connection side straight extension (ref. 3).
4	Definition of the opposite connection straight extension (ref. 4).
5	Definition of the connection side total extension (ref. 5).
6	Definition of the opposite connection side total extension (ref. 6).

3.6 X-Factor

3.6.1 Definitions



Calibration factors		
Reference temperature (°C)	20.0	← 1
Ref. max. Line-Line voltage, rms (V)	380.0	← 2
Voltage drop limit, rms (V)	100.0	← 3
Winding resistance factor	1.0	← 4
End winding inductance factor	1.0	← 5

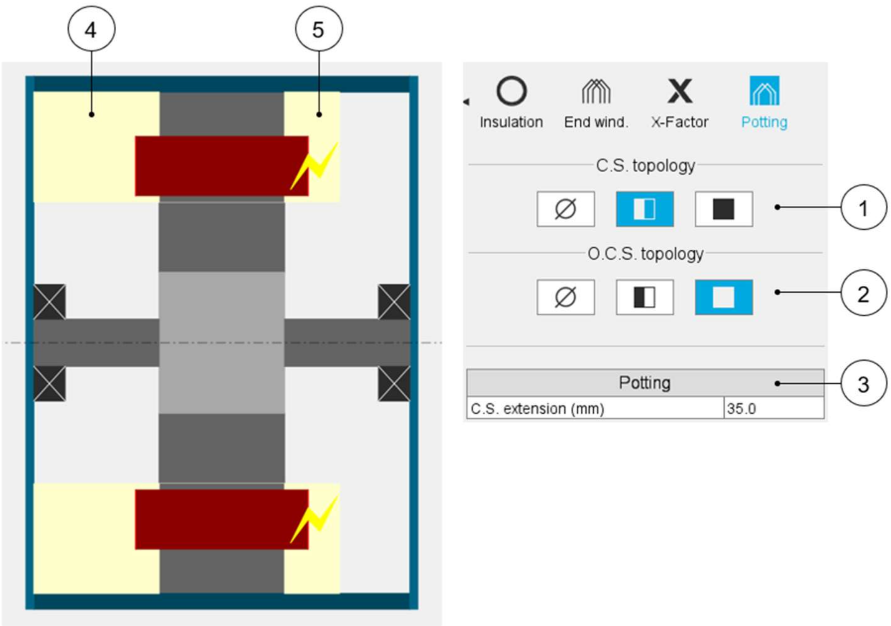
List of calibration factors

1	The reference temperature. First, resistance values are computed by considering a temperature equal to 20°C. However, the user can also define his own reference temperature to compute the corresponding phase resistance and Line-Line resistance values. **Note**: This reference temperature is used only in the winding design environment. The test temperatures are defined in the test settings (refer to TEST chapter).
2	Reference maximum Line-Line voltage. It allows evaluating the voltage drop between the conductors.
3	Voltage drop limit between 2 superimposed conductors. This limit is given to better visualize the voltage threshold which shall not be exceeded (see the displaying of colored fields in the table).
4	Setting of the “Resistance factor”. It allows adjusting computation result of resistance with resistance measurement. Thus, the resulting phase resistance value is considered.
5	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.

3.7 Potting

3.7.1 Overview - Definitions

“Potting” section is available only when the housing is defined with a frame (circular or square shape).



Definition of the topology and dimensions of the potting around the end-winding

1	Button to define a potting with only radial contact (at connection side in this example)
2	Button to define a potting with radial and axial contacts (at opposite connection side in this example).
3	Dimensions for defining the selected potting.
4	Extension of potting with both contact axial and radial.
5	Extension of potting with radial contact only.

4 FIELD WINDING

4.1 Overview

4.1.1 Introduction

This kind of winding architecture is used to build the rotor poles of the wound field synchronous machines.
The rotor field winding has a lot of similarities with the 3-phase winding. Therefore, in each sub-section of the Rotor Winding context, only the differences compared to the 3-phase winding are mentioned. For further information regarding basic knowledge and terminology about electrical winding, please refer to the user help guide: “Windings” which is dedicated to the winding design General user information.

4.1.2 Design

A scrolling selection bar helps to choose the section in which one can define the winding settings.
Here are the sections available to design the winding step by step:

- “Scheme” to build the winding architecture.
- “Coil” to set how the coil is defined and to see how the pole is wound.
- “Insulation” to define all the winding insulations.
- “End winding” to define the dimensions of the end-windings.
- “X-Factor” to adjust phase resistance and end-winding inductance.

Sections to design the field winding step by step

Note: In the software the field winding datasheet, the parameters written in blue correspond to user input parameters and the parameters written in black correspond to data resulting from computations.

4.1.3 Terminology

Refer to the section “Terminology – Illustration”.

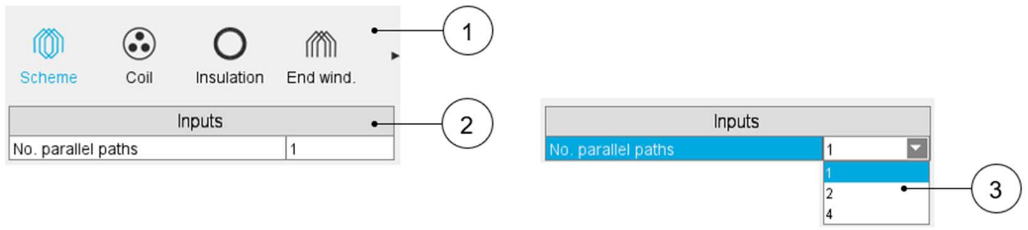
4.1.4 Classical winding outputs

Please refer to the section “Winding / Winding outputs”.

4.2 Scheme

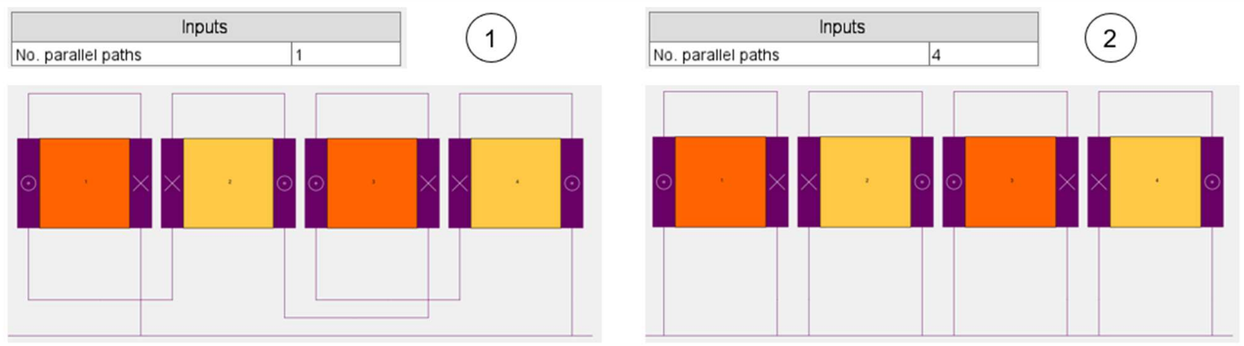
4.2.1 Overview

Here are below the winding scheme user inputs.



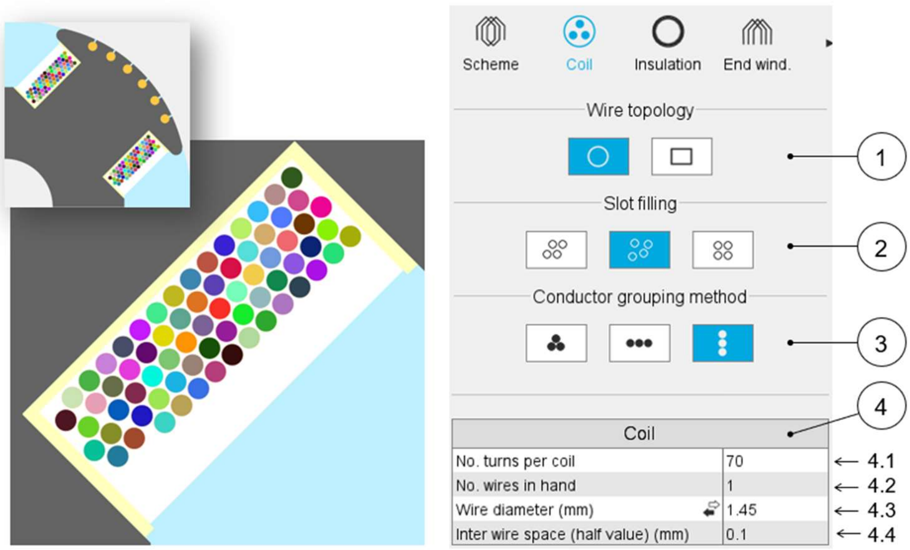
Inputs to define the field winding architecture = winding scheme	
1	Sections to design the winding step by step.
2	List of user inputs to define the winding architecture. One user input to be defined: the number of parallel paths. Note: The possible numbers of parallel paths are automatically computed and proposed to the user (3). When the user selects the number of parallel paths, the connections on the field winding scheme are automatically updated.

4.2.2 Parallel paths



Building the winding architecture – The number of parallel paths is represented in the winding scheme	
1	Example where the No. parallel paths is equal to 1.
2	Example where the No. parallel paths is equal to 4.

4.3 Coil



Definition of the coil – Case of Circular wires

1	Definition of the wire topology, Circular or Rectangular
2	Choice of the method to fill the slot: Three ways are allowed to fill the slot: Orthocyclic, Random, Layer. See below illustrations.
3	Choice of method to group the elementary wires. Three ways allow to fill the slot: Grouped, Horizontal, Vertical.
4	Description of the coil and dimensions of elementary wires + twist options.
4.1	Number of turns per coil
4.2	Number of wires in parallel in a conductor (per turn) i.e. number of wires in parallel in each conductor.
4.3	Wire dimensions - Diameter (without insulation) (1)
4.4	Minimum distance between insulated wires to be considered for modelling inside the Flux® 2D environment. When there is no wire insulation, Inter-wire space represents the minimum distance between the bar wires (2).

Note: 1 - Different ways are available to choose the wire diameter:

- Directly entering the value of the wire diameter (without insulation)
- Choose the diameter from the American Wire Gauge table in which available wire diameters are listed (without insulation)
- Choose the diameter from the Metric Wire Gauge table in which available wire diameters are listed (without insulation)

Note: 2 - Illustration of inter-wire space
This value is considered in Motor factory for computing the filling factor, and while exporting a model into Flux® environment (EXPORT area) for building the corresponding finite element model.

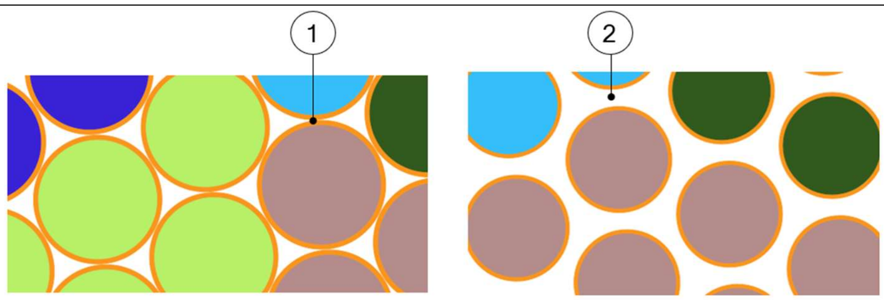


Illustration of inter-wire space

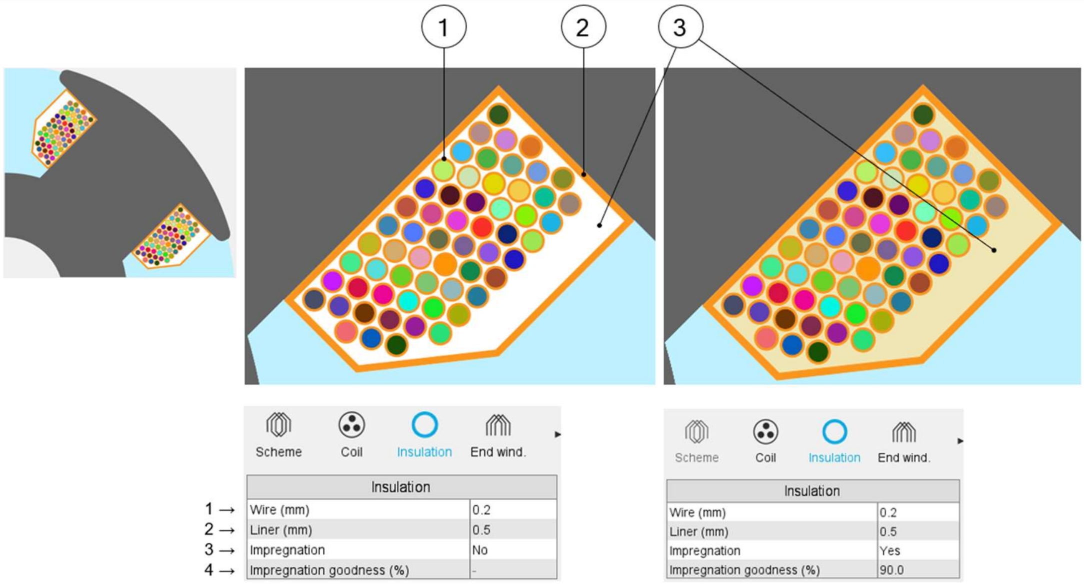
1	Default value for inter-wire space and the corresponding pictorial display.
2	Impact of a higher value for inter-wire space

4.4 Insulation

Compared to the 3-Phase Winding, the only difference in the insulation section is that for the pole field winding, there is no phase separator.

- Types of insulators
- Impregnation

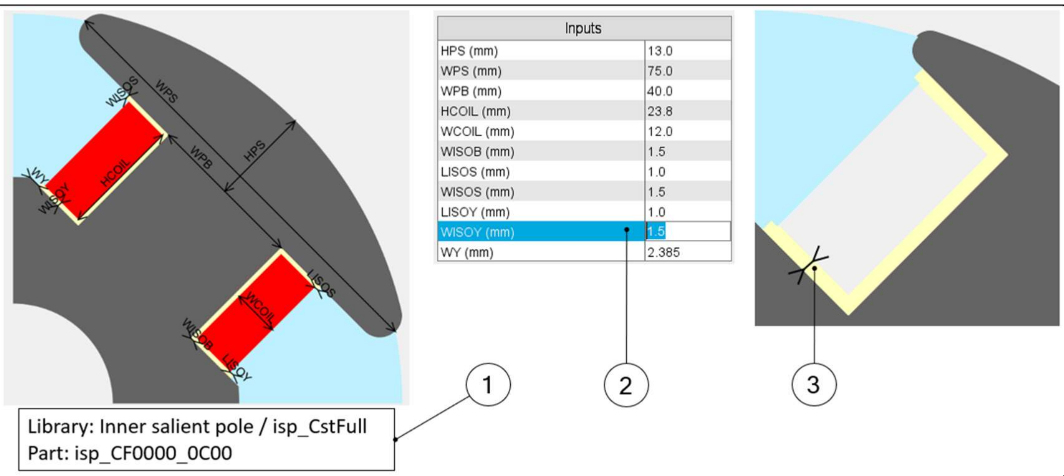
Insulation settings allow the user to describe the coil insulation (wire, liner, impregnation) and how to fill the slot.



Definition of the field winding insulation	
1	Wire insulation (setting and illustration)
2	Liner insulation (setting and illustration)
3	Impregnation (setting and illustration with two options, Yes / No)

Note: The liner thickness adjustment can be defined via part definition

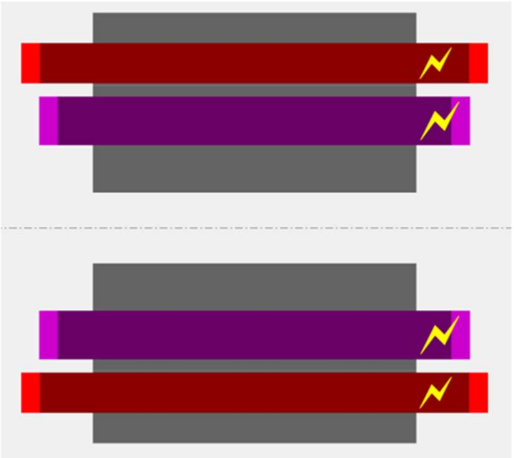
The liner thickness is constant on all sides of the coil area which is defined by the part definition. The thickness of liner on each side can be adjusted by adding insulation regions to the pole part. A typical example can be found in the part isp_CB0000_0C00.

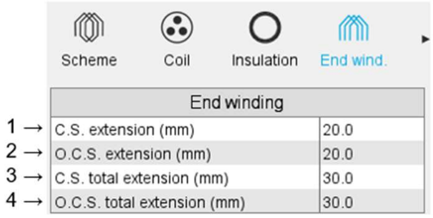


Definition of liner thickness via part definition – Example with isp_CF0000_0C00 part	
1	The isp_CF0000_0C00 part can be found in the isp_CstFull library
2	The parameters, such as WISOY allow adjusting the isolation thickness of the winding on the yoke side. Use WISOB and WISOS to adjust the isolation thickness on the pole body and pole shoe sides.
3	The arrow shows the dimension corresponding to WISOY

4.5 End winding

Note: Compared to the 3-Phase Winding, the only difference in the insulation section is that for pole DC winding, there is only one type of end winding, which is the U-shape end winding. Please refer to the user help guide: “Windings” for further technical details about the topology of end winding and its dimensions.



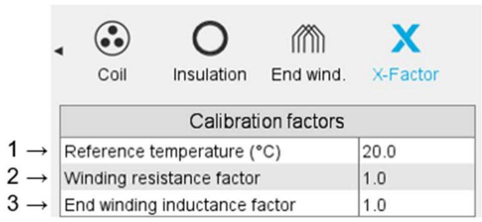


Definition of the end winding

1	Definition of the connection side straight extension
2	Definition of the opposite connection straight extension
3	Definition of the connection side total extension
4	Definition of the opposite connection side total extension

4.6 X-Factor

4.6.1 Definitions



List of calibration factors

1	The reference temperature. First, resistance values are computed by considering a temperature equal to 20°C. However, the user can also define his own reference temperature to compute the corresponding phase resistance and Line-Line resistance values. **Note**: This reference temperature is used only in the winding design environment. The test temperatures are defined in the test settings (refer to TEST chapter).
2	Setting of the “Resistance factor”. It allows adjusting computation result of resistance with resistance measurement. Thus, the resulting phase resistance value is considered.
3	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.

5 DC WINDING

5.1 Overview

This kind of winding architecture is used by DC machines to define rotor winding.
The DC winding has a lot of similarities with the 3-phase winding but also many specific traits when referring to architecture.
Therefore, only the architecture is described in this section since the coil, insulation, end-winding and x-factor tabs does not have any important modification when compared with the 3-phase classical winding.
For further information regarding basic knowledge and terminology about electrical winding, please refer to the previous sections which is dedicated to the winding design general user information.

Here is the homepage for the design of the rotor winding.

5.1.1 Design

A scrolling selection bar helps to choose the section in which one can define the winding settings.
Here are the sections available to design the winding step by step:

- “Scheme” to build the winding architecture.
- “Coil” to set how the coil is defined.
- “Insulation” to define all the winding insulations.
- “End winding” to define the dimensions of the end-windings.
- “X-Factor” to adjust phase resistance and end-winding inductance.

Sections to design the DC winding step by step

Note: In the DC winding datasheet, the parameters written in blue correspond to user input parameters and the parameters written in black correspond to data resulting from computations.

5.1.2 Terminology

Refer to the section “Terminology – Illustration” dedicated to DC winding.

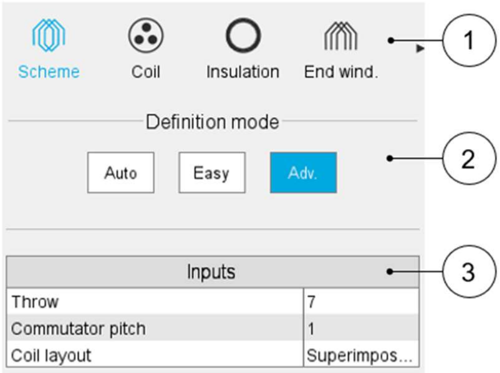
5.1.3 Classical winding outputs

Please refer to the section “Winding / Winding outputs” dedicated to DC winding.

5.2 Scheme

5.2.1 Overview

Here are below the winding scheme user inputs.

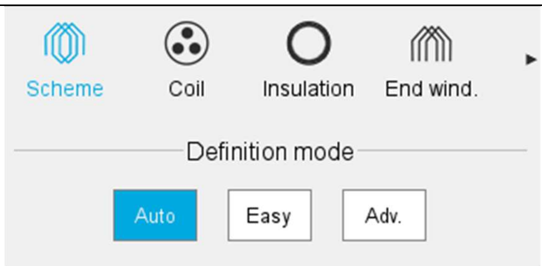


Inputs to define the DC winding architecture = winding scheme	
1	Sections to design the winding step by step.
2	Winding definition mode: Automatic, Easy or Advanced. See below section dedicated to the construction of the winding architecture.
3	List of user inputs to define the winding architecture. See the corresponding definition below.

5.2.2 Definition modes

There are three winding definition modes: Automatic, Easy or Advanced. See below the corresponding illustration.

5.2.3 Automatic

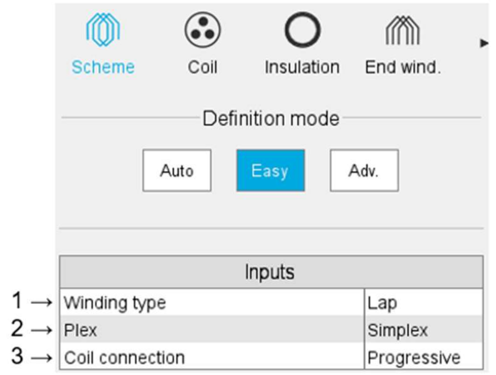


Definition mode – **Automatic** mode

Note: No parameters are needed for automatic mode.
The automatic mode always creates the most basic winding corresponding to the number of poles and slots defining the machine topology. This scheme corresponds to a simplex lap winding with progressive connection. Values for throw and commutator pitch are defined in the table below.

Basic winding variables	**Value in easy mode**
Throw (coil pitch)	round (number of slots / number of poles)
Commutator pitch	1

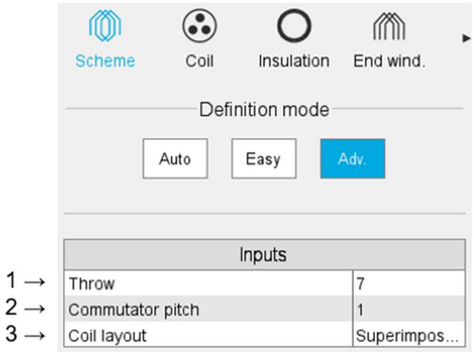
5.2.4 Easy



Definition mode – **Easy** mode

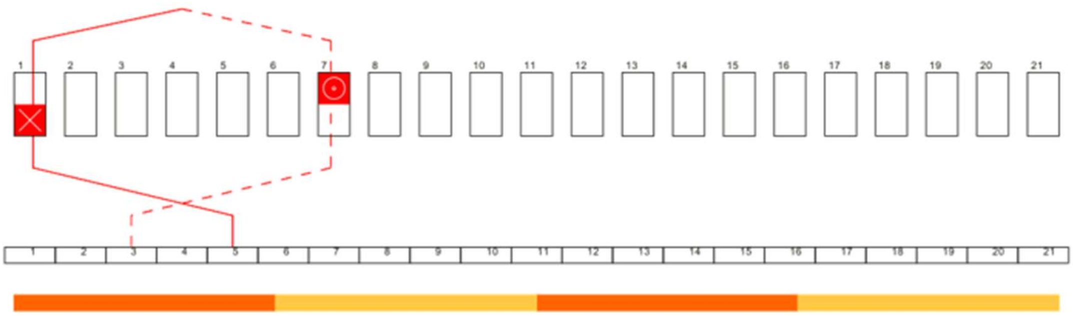
1	Selection of winding type. **Lap:** The ends of one coil are connected to consecutive commutation segments (i.e., the commutator pitch absolute value is equal to 1 for simplex winding) **Wave:** The ends of one coil are connected to commutator segment separated by an angular distance as close as two pole pitch as possible (for simplex winding)
2	Selection of the plex. The plex is a measure of how many commutator segments can touch a particular brush at the same time. The number of parallel paths in the machine circuit is directly proportional to its plex. Even if there is not a theorical limitation to its value, for practical designs three plex are considered: simplex (plex=1), duplex (plex=2) and triplex (plex=3).
3	Selection of coil connection: Progressive or regressive Progressive connection: Commutator segments are connected following the same direction as winding (i.e., commutator pitch is positive). Regressive connection: Commutator segments are connected following opposite direction as winding (i.e., commutator pitch is negative). Illustration of these two types of winding is given in next sections.

5.2.5 Advanced



Building the winding architecture - **Advanced** mode

1	Selection of the thrown (coil pitch) The proposed solutions depend on the number of slots and the number of poles. Throw <= ceil (number of slots / number of poles)
2	Commutator pitch. Number of commutator segments between the segment connected to the coil input and the segment connected to the coil output. Only the options compatible with a valid lap/wave winding are offered.
3	Definition of the coil layout i.e. how the coil sections are distributed into the slot. The two possible choices are: • Superimposed = At least two superimposed coils into one slot • Adjacent = At least two adjacent coils into one slot By default, the superimposed option is selected.



Graphical example of a winding defined with throw =5, commutator=-2, superimposed layout
It corresponds to a lap, duplex, regressive winding.

5.3 Coil

This section has the same definition as the classical winding topology. Please refer to the corresponding section.

5.4 Insulation

This section has the same definition as the classical winding topology. Please refer to the corresponding section.

5.5 End winding

This section has the same definition as the classical winding topology. Please refer to the corresponding section.

5.6 X-Factor

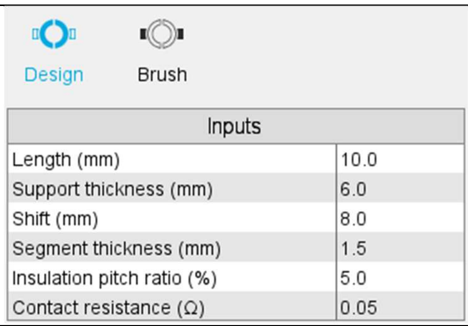
This section has the same definition as the classical winding topology. Please refer to the corresponding section.

6 COMMUTATOR

6.1 Overview

A scrolling selection bar helps to choose the section in which one can define the commutator settings.
Here are the sections available to design the winding step by step:

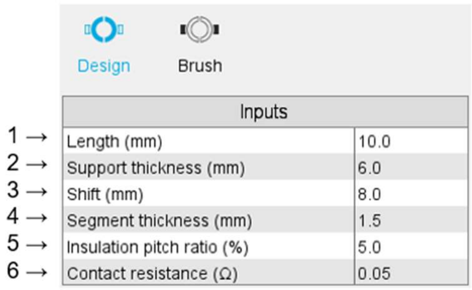
- "Design" to define the main characteristics of the commutator.
- "Brush" to set how the coil is defined and to see how the slots are filled.



Sections to design the commutator step by step

Note: In the commutator datasheet, the parameters written in blue correspond to user input parameters and the parameters written in black correspond to data resulting from computations.

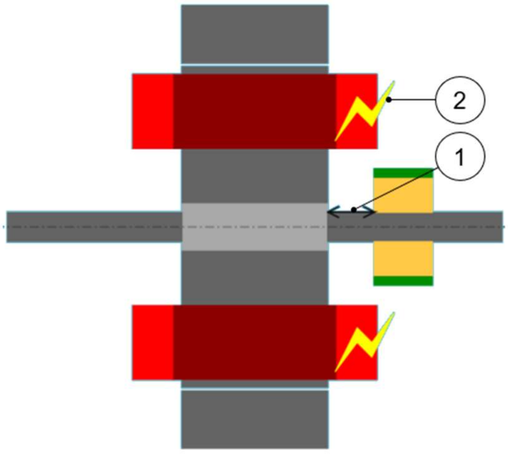
6.2 Design



Commutator geometrical parameters - List

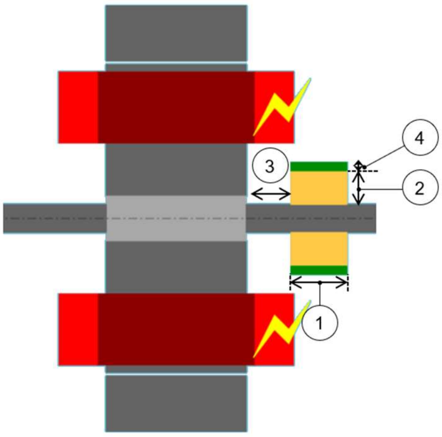
1	Commutator axial length
2	Thickness of the not conducting material that is supporting the commutator segments. Since it has cylindrical form it corresponds to its radius.
3	Commutator shift
4	Thickness of the conductive commutator segments.
5	Angular ratio of the insulation between commutator segments
6	Contact resistance between the brushes and the commutator segments

Note: By definition, the commutator is always placed in the connection side (C.S.) which is identified by a yellow lighting.



Commutator geometrical parameters - Illustration

1	Commutator shift Note: Dimensions are illustrated with arrows
2	The commutator is always placed in the connection side (C.S.) which is identified by a yellow lighting



Commutator geometrical parameters - Illustration

1	Length
2	Support thickness
3	Shift
4	Segmentation thickness

6.3 Brush

6.3.1 Overview

This section allows to stablish global parameters, both geometrical and electrical and to introduce brush related parameters.

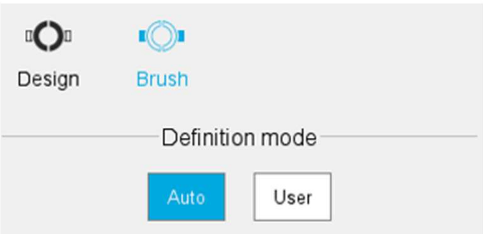
There are two options to choose the commutator-brush definition mode:
• Auto: Brushes dimensions and angular position are automatically calculated by FluxMotor to get the best fit with the defined winding.
• User: Brushes dimensions and angular position are defined by the user

The visualization of the commutator topology including brushes are displayed in the motor radial and axial views.

6.3.2 Definition modes

There are two definition modes: Automatic, and user.

6.3.3 Automatic

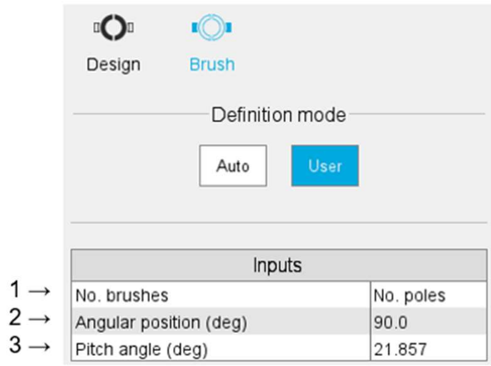


Definition mode – **Automatic** mode

Note: The number of brushes, the angular position of the reference brush, and the pitch angle of a brush are automatically defined. Here are the corresponding value set:

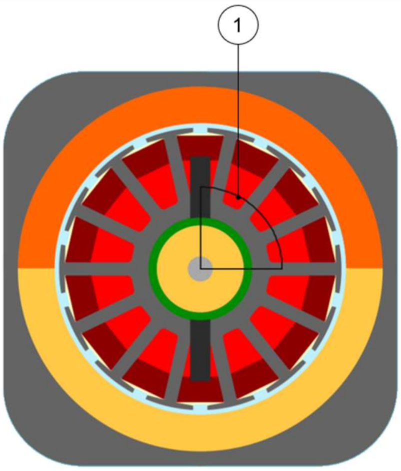
- Number of brushes = Number of poles.
- Angular position of the reference brush (polarity +) = center of a north pole (for lap winding) and center of a south pole (for wave winding).
- Pitch angle of a brush= 0.85 times the segment commutator pitch for simplex winding (1.85 for duplex and 2.85 for triplex).

6.3.4 User



COMMUTATOR – Brush - Overview

1	Number of brushes. Only unblocked for wave winding. Default value = Number of poles.
2	Angular position of the reference brush (polarity +). Default value: Center of a north pole (for lap winding) and center of a south pole (for wave winding).
3	Pitch angle of a brush. Default value: 0.85 times the segment commutator pitch for simplex winding (1.85 for duplex and 2.85 for triplex)



Brush angular position - Illustration	
1	Brush angular position - Angles are illustrated in the visualization