Altair® FluxMotor® 2023

Motor Factory - 3-Phase winding design

General user information

Altairhyperworks.com

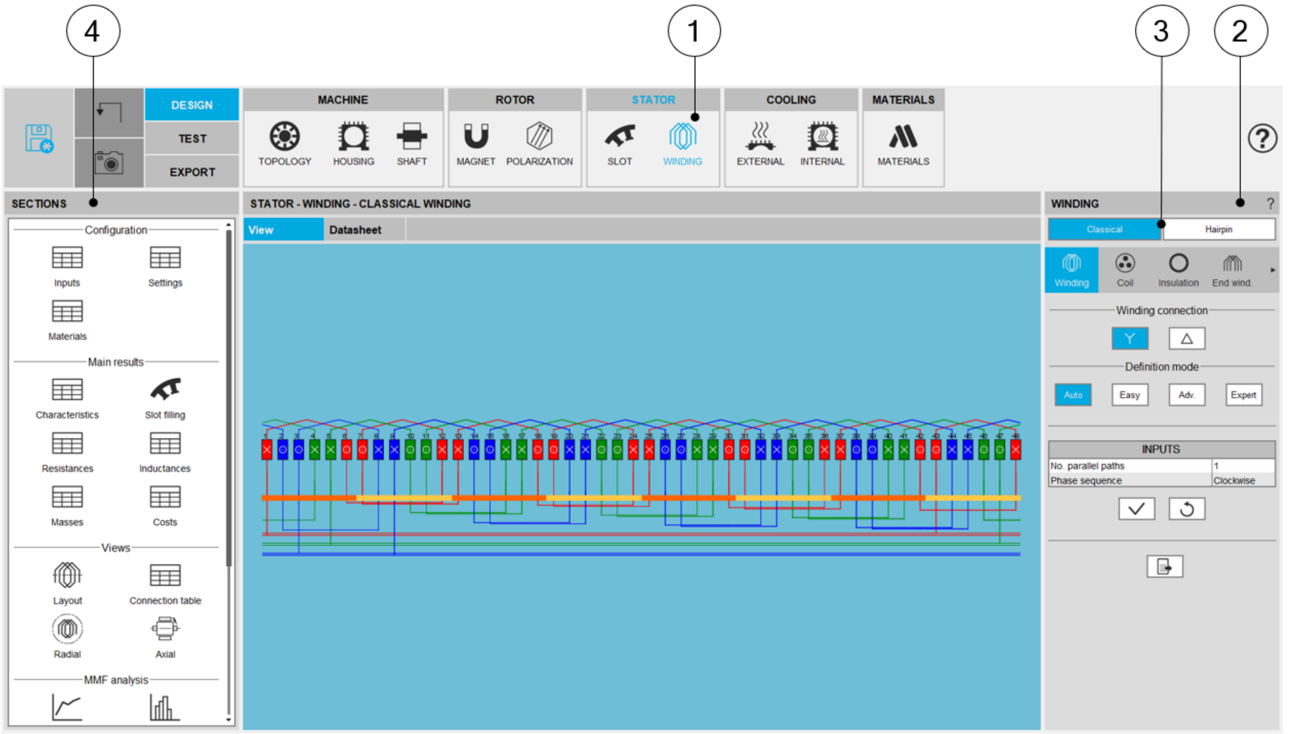
Contents

1 WINDING DESIGN ENVIRONMENT

1.1 Overview

In Motor Factory, two types of winding can be designed: Classical windings or hairpin winding types.

Here is the home page for designing both classical and hairpin winding.



WINDING design area – Area dedicated to classical windings	
1	Selection of the STATOR subset: WINDING panel (Click on the icon WINDING)
2	Winding input parameter panel dedicated for designing of the winding (either classical or hairpin technology windings)
3	Buttons to select the winding type “classical or hairpin” (here classical winding is selected – Highlighted in blue).
4	Shortcuts to easily navigate in the output sections

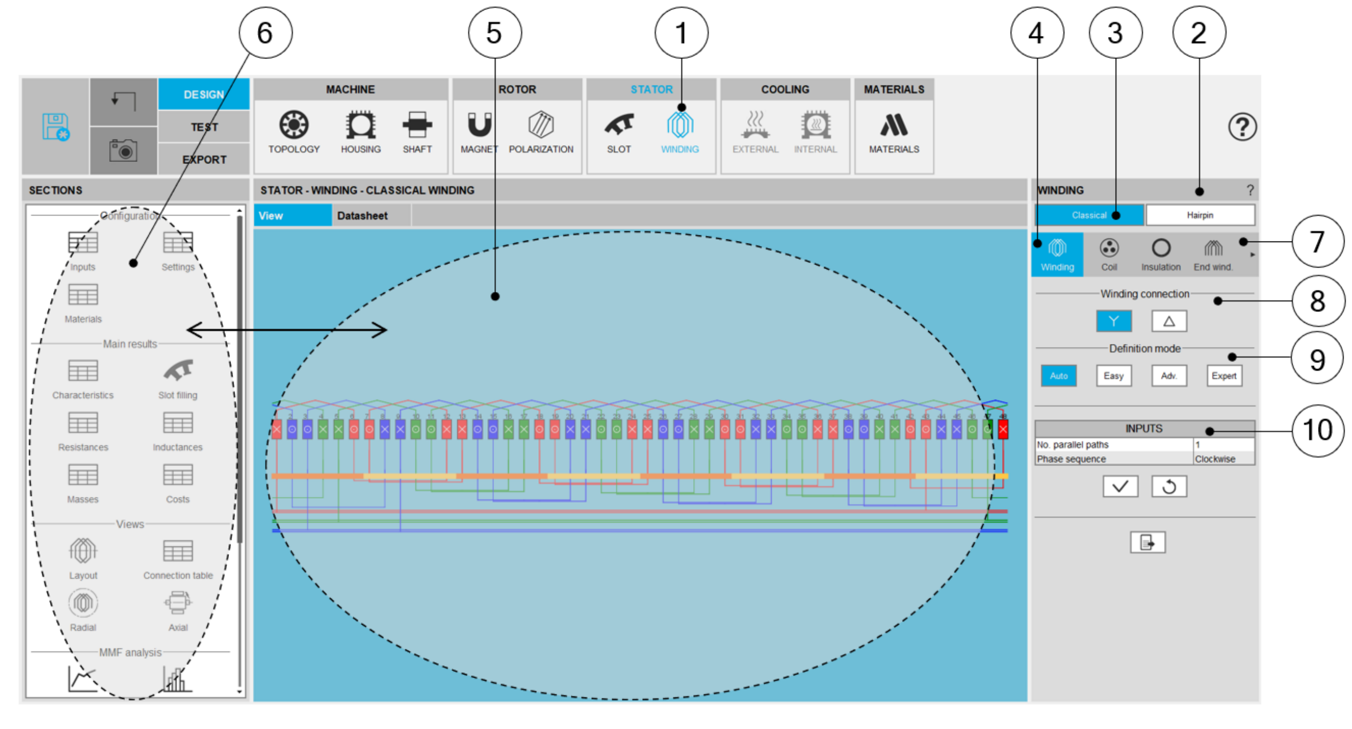
The following sections describe the GUI dedicated to the classical and hairpin winding design.

The sections 2 & 3 are dedicated to classical winding design whereas sections 4 & 5 concerns the hairpin winding design.

1.2 Winding design area

1.2.1 Home page

For both types of winding, whether classical or hairpin, the home page characteristics are the same. The following picture illustrates the main areas of the home page which is displayed for the classical winding.



WINDING design area – Classical winding - Overview	
1	Selection of the STATOR subset: WINDING panel (Click on the icon WINDING)
2	All the required user inputs to define the winding are available in the “WINDING” panel (right part).
3	Selection of the classical winding design (Highlighted in blue)
4	Winding settings allow describing the winding architecture
5	Once a winding is defined, the corresponding results are automatically displayed in the form of a winding report. Visualization of the winding characteristics (inputs, settings, materials, etc) are possible. Scrollbars allow browsing the whole document rapidly and giving an overview of all the results. Using scrollbars, complete data can be accessed and visualized.
6	Shortcuts for displaying the corresponding section of the winding report.
7	A section scrolling bar allows choosing the section in which user inputs are defined. Scrolling selection bar where Winding architecture, Coil, Insulation, End-winding, X-Factor and Potting sections can be selected
8	Choice of the winding connection: Y (Wye) or Δ (Delta)
9	Four modes of winding allow to **define and build the winding architecture**.
Auto	**Automatic** mode, used as default.
Easy	**Easy** mode, to choose solution among those FluxMotor® proposes.
Adv.	**Advanced** mode, to allow the user to define any specific input parameters.
Expert	**Expert** mode, to set the connection table.
10	User input parameter fields to enter the values according to the considered mode.

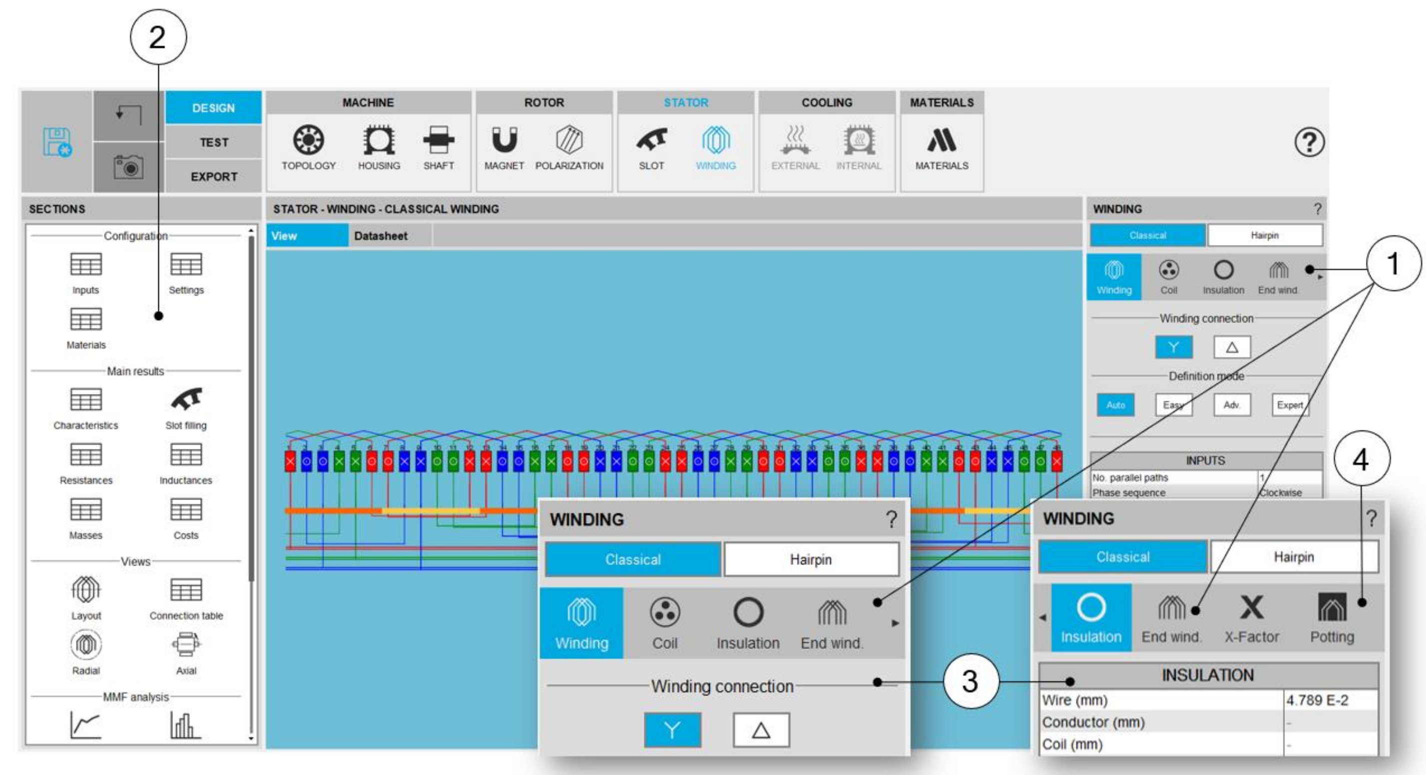
Note: This usage mode is applied for hairpin winding environment as well.

1.2.2 Selection of sections

A scrolling selection bar helps to choose the section in which one can define the winding settings.
The winding can be built step by step. One can access the different sections by clicking on the following buttons:

- “Winding” 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

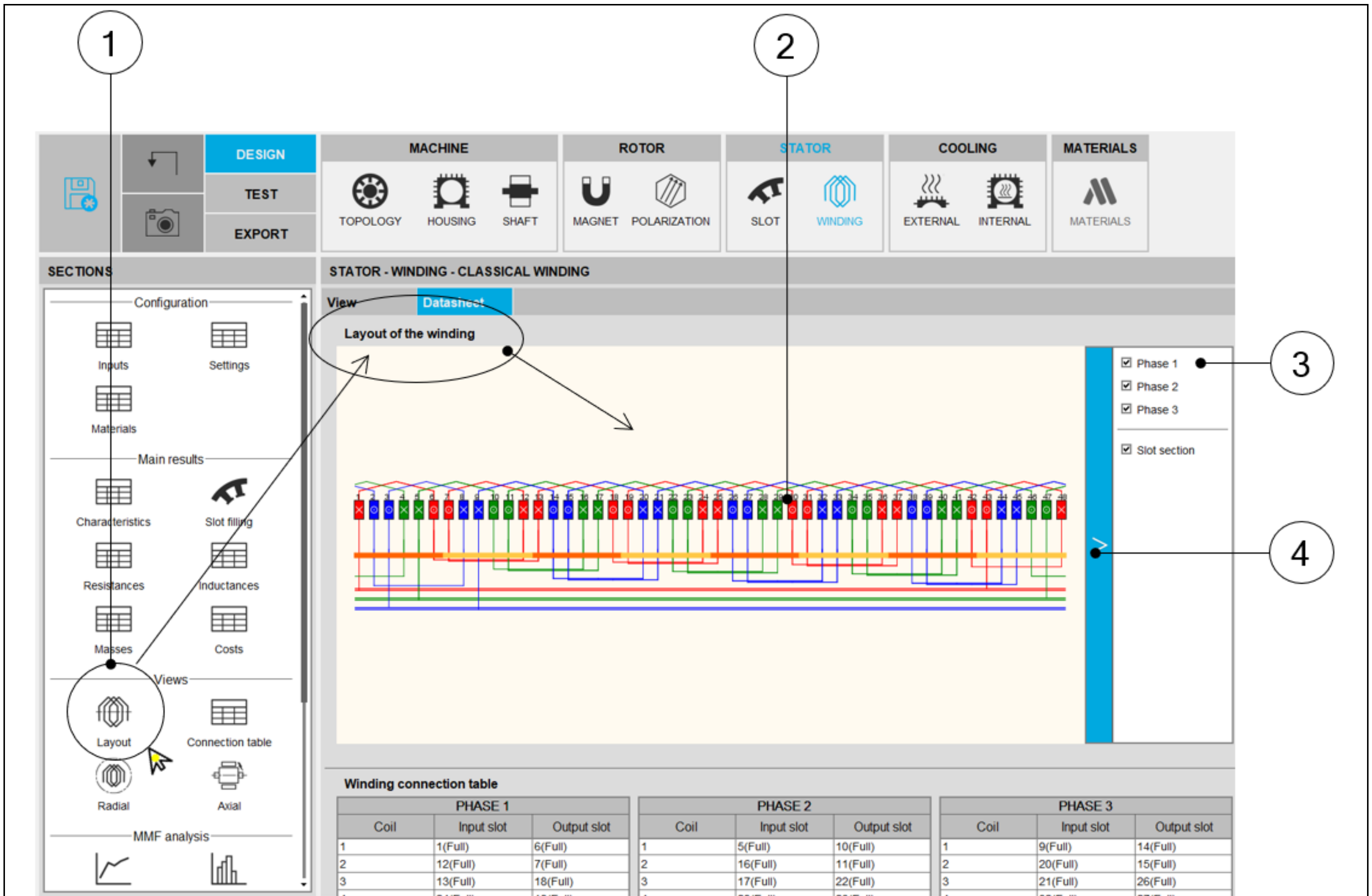
Note: “Potting” section is available only when the housing is defined with a frame (circular or square shape).



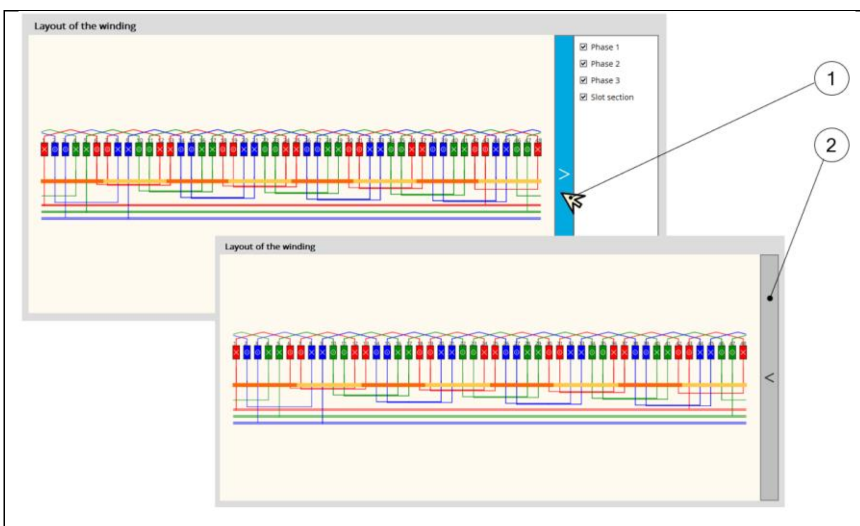
Scrolling selection bar – Winding environment	
1	Scrolling selection bar, where Winding, Coil, Insulation, End-winding, X-Factor and Potting sections can be selected
2	Section data representing shortcuts for analyzing the input and output parameters
3	Arrow symbol allows the user to scroll the bar to reach other sections (on the right or the left) when needed
4	The bar slides on the right to allow reaching Potting section

Note: This mode of section selection is applied for hairpin winding environment as well.

1.2.3 Information about Winding area GUI

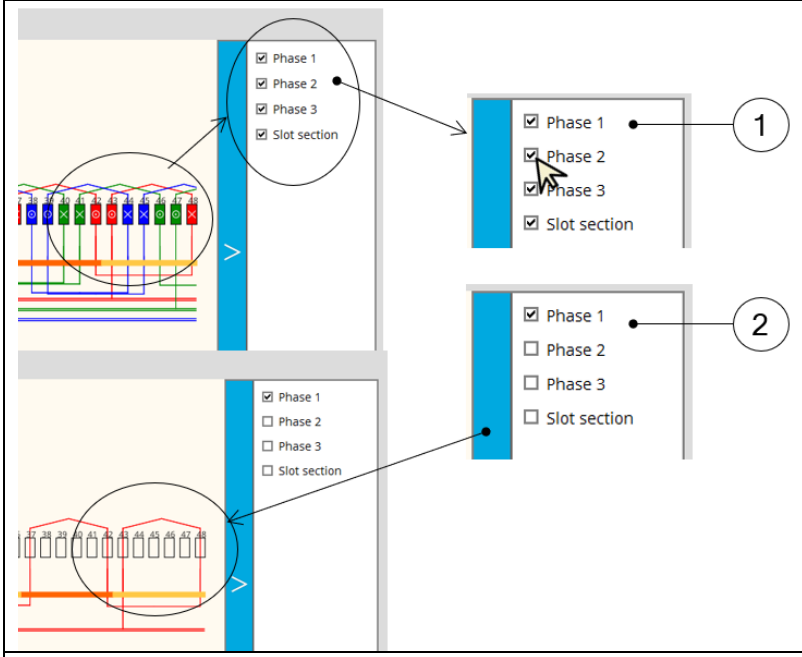


WINDING design area – Information about GUI	
1	Shortcuts for displaying the corresponding section of the winding report.
2	In the current example, select “Layout” displays the layout of the winding.
3	Picture legends are available on the right part of the screen.
4	The legends can be folded right to save space: see below.



1	Click on the blue band.
2	The legend is folded right: there is more space to analyze pictures. Once the legend is folded, it is possible to unfold it by clicking on the grey band.

Process to fold or unfold the legends of graphics

	1	All the legend items are checked. The corresponding phases and the slot section are displayed. (With the phase color and sign to indicate the orientation of the electrical current).
	2	Only the Phase 1 is checked. Phase 2 and 3 are no longer displayed along with the slot section.

Process to manage visualization of phases on the picture

1.3 Advice for use

The number of slots can be chosen over the range [3, 2400].
The number of poles can be chosen over the range [2, 400].

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].

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

A table representing a selection of combinations of number of poles and number of slots is presented below.
In this table the number of slots goes from 3 to 90 and the number of poles goes from 2 to 80.

To be noted:
a) 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.

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

c) 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/nth 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.

Poles \ Slots	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

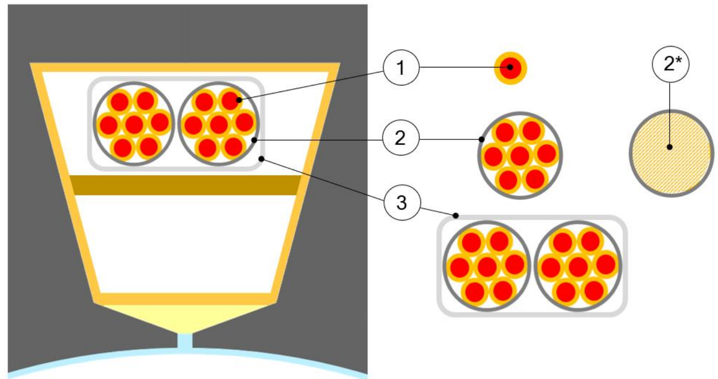
Combinations No. poles / No. slots

2 CLASSICAL WINDING DESIGN

General information: 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.

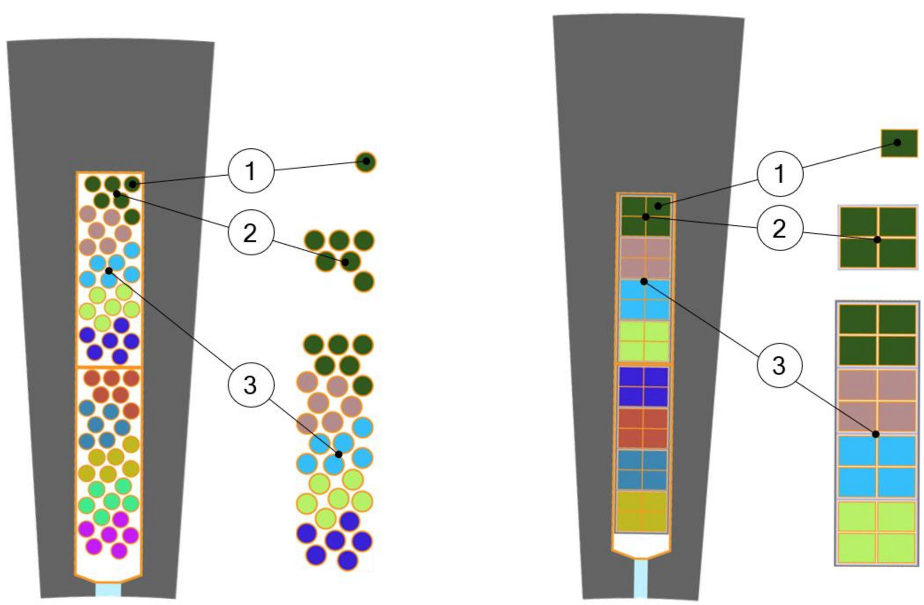
2.1 Terminology – Illustration

2.1.1 Theoretical definition



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).

2.1.2 Terminology – Application in Motor Factory



Slot composition	
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).

2.2 Classical winding architecture - Inputs

2.2.1 Overview – Definitions

The following inputs define the winding architecture

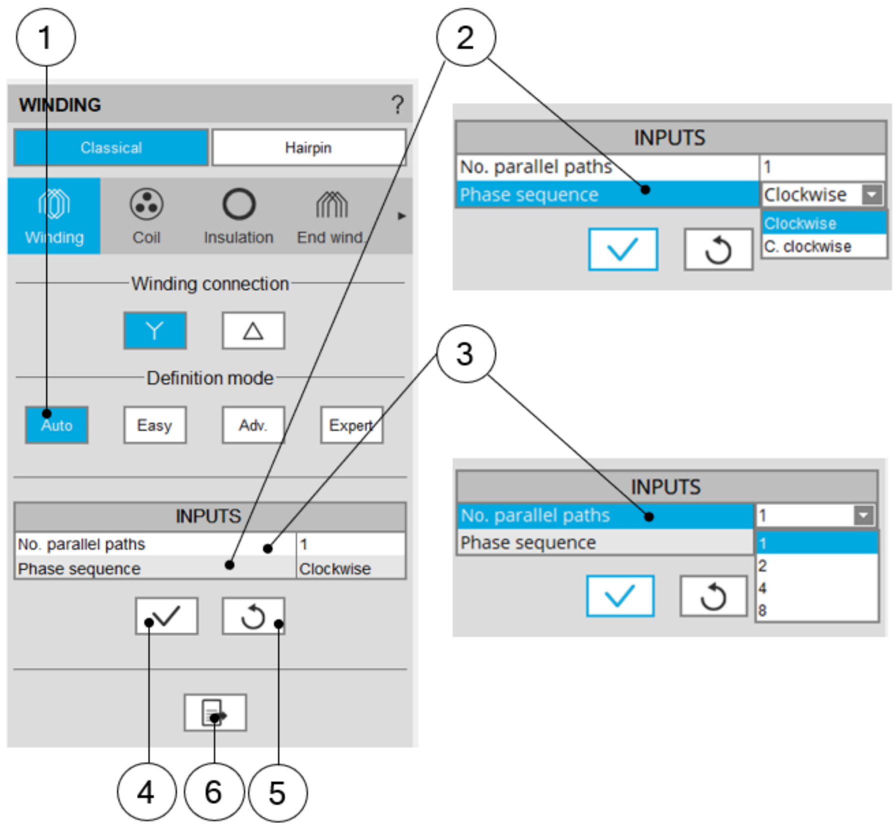
Label	Symbol	Tooltip, note, formula
Winding connection	Connect	Winding connection (Y – Wye or Δ - Delta)
Definition mode	*	Winding definition mode: Automatic, Easy, Advanced or Expert. See below section dedicated to the construction of the winding architecture
No. parallel paths	P_{paths}	Number of parallel paths (all modes).
Phase sequence	*	Phase sequence (all modes).
Coil pitch	τ_{coil}	Coil pitch = number of slot pitch between coil input and coil output (Easy mode / Advanced mode).
No. layers	N_{layers}	Number of layers – 1 or 2
Winding type	*	Winding type: Lap, Concentric or manual. Note: “Manual” characterizes the “winding type” when the chosen “Winding mode” is “Expert mode”
No. Coils / pole / phase	q	Number of slots per pole and per phase. $q = \frac{Number\ of\ slots}{2p \times m}$ (p is the number of pole pairs and m is the number of phases)

2.2.2 Automatic mode

2.2.2.1 User input parameters

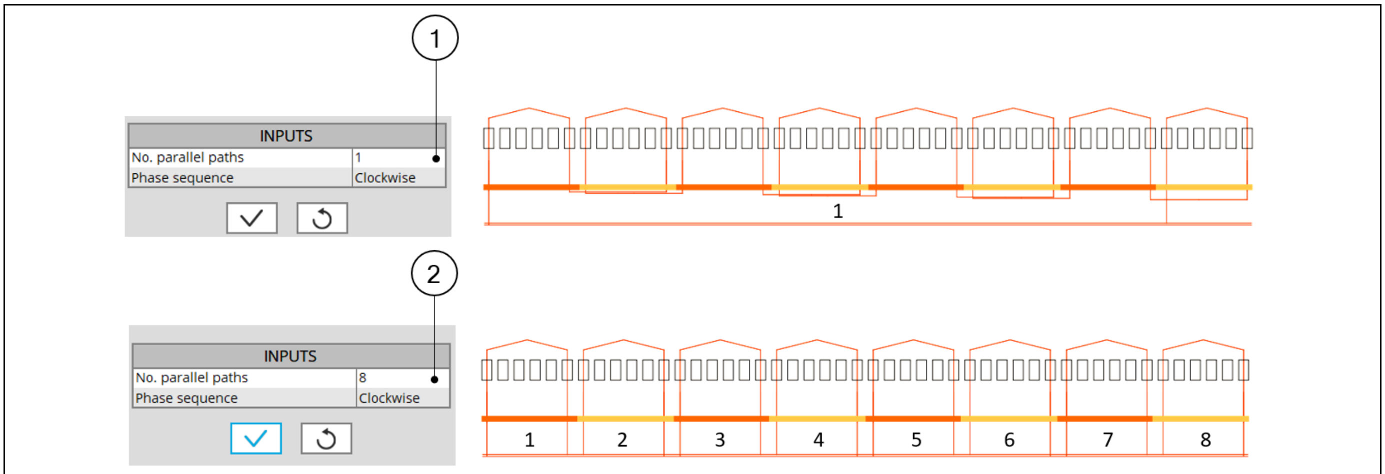
Label	Symbol	Tooltip, note, formula
Phase sequence	*	Phase sequence (all modes).
No. parallel paths	P_{paths}	Number of parallel paths (all modes).

2.2.2.2 Building the winding architecture – Automatic mode – Main principles



Building the winding architecture - **Automatic** mode	
1	Selection of **Automatic** mode for building the winding architecture.
2	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counterclockwise (Clockwise or C. clockwise). The rotation direction is defined when facing the machine on the connection side.
3	Number of parallel paths. 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. See examples below.
4	Button to apply inputs. Pressing the enter key twice applies inputs too.
5	Button to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
6	Icon to export winding data into a text file

2.2.2.3 Parallel paths



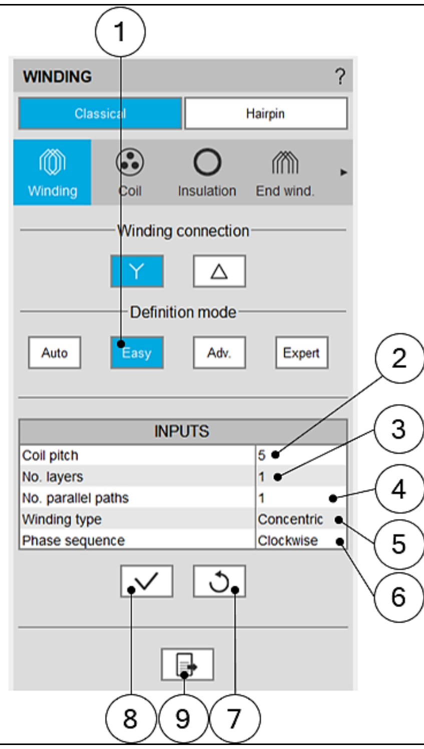
Building the winding architecture – The number of parallel paths are represented in the winding scheme	
1	Example where the No. parallel paths is equal to 1.
2	Example where the No. parallel paths is equal to 8.

2.2.3 Easy mode

2.2.3.1 User input parameters

Label	Symbol	Tooltip, note, formula
No. Layers	N_{Layers}	Number of layers - 1 or 2 (Easy mode).
Coil pitch		Coil pitch = number of slot pitch between coil input and coil output (Easy mode / Advanced mode).
Winding type	*	Winding type - Lap or Concentric (Easy mode / Advanced mode).
Phase sequence	*	Phase sequence (all modes).
No. parallel paths	P_{paths}	Number of parallel paths (all modes).

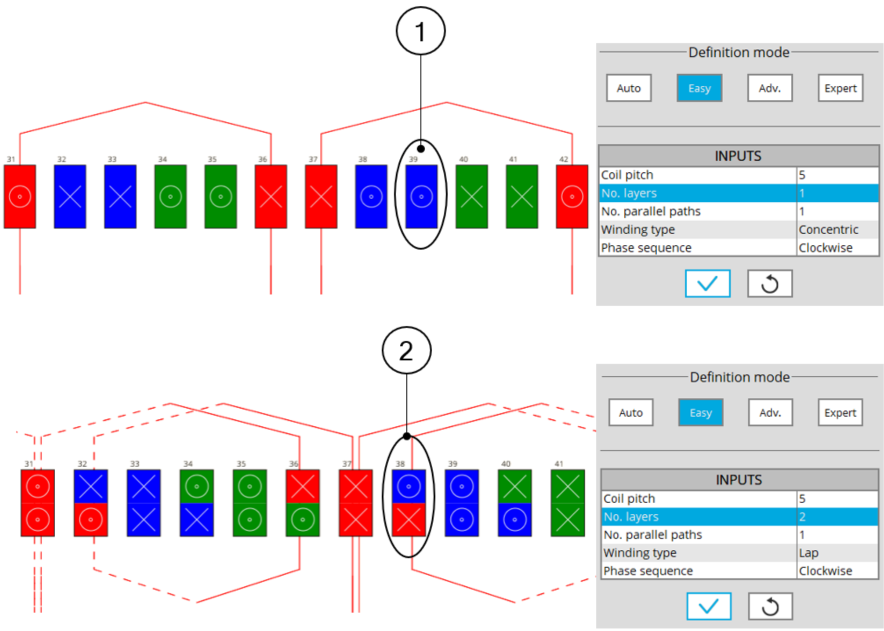
2.2.3.2 Building the winding architecture – Easy mode – Main principles



Building the winding architecture - **Easy** mode

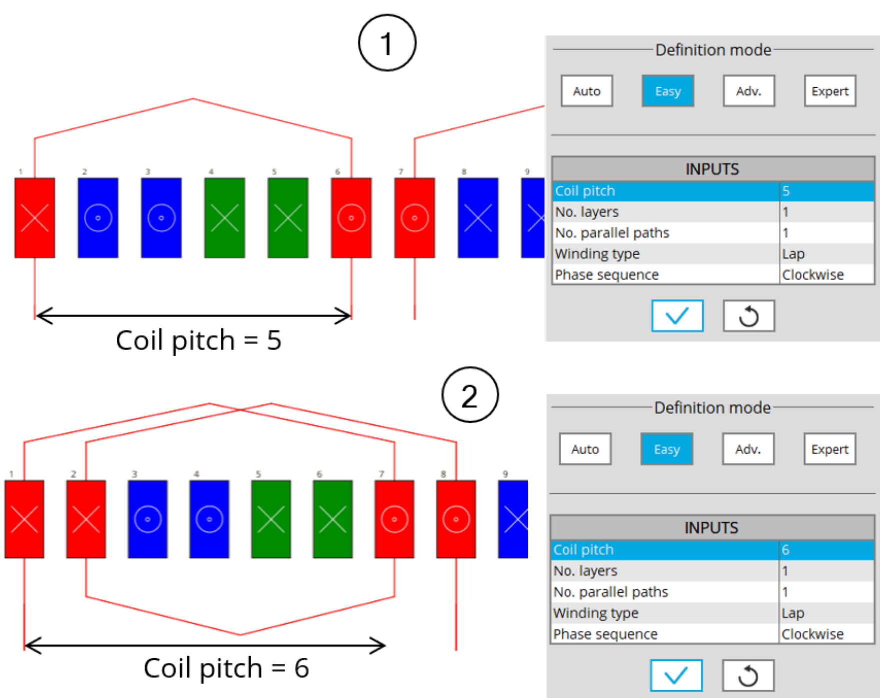
1	Selection of the **Easy** mode for building the winding architecture.
2	Selection of coil pitch. The proposed solutions depend on the number of slots and the number of poles. Example 1: With 12 slots and 10 poles, only one solution is proposed: a tooth winding. Example 2: With 48 slots and 8 poles, two solutions are proposed: 5 or 6. For various possibilities, a list of solutions are proposed.
3	Selection of the number of layers. The proposed solutions depend on the number of slots and the number of poles. Example: With 12 slots and 10 poles, only one solution is proposed: 1 layer. The three possible cases are illustrated below.
4	Number of parallel paths. 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. See examples in Auto mode chapter.
5	Selection of winding type: Concentric or Lap. Illustration of these two types of winding is given below.
6	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.
7	Icon to restore default input values. Default values are those which defined the winding architecture by using the automatic mode.
8	Icon to apply inputs. Pressing the enter key twice applies inputs too.
9	Icon to export winding data into a text file

2.2.3.3 Number of layers



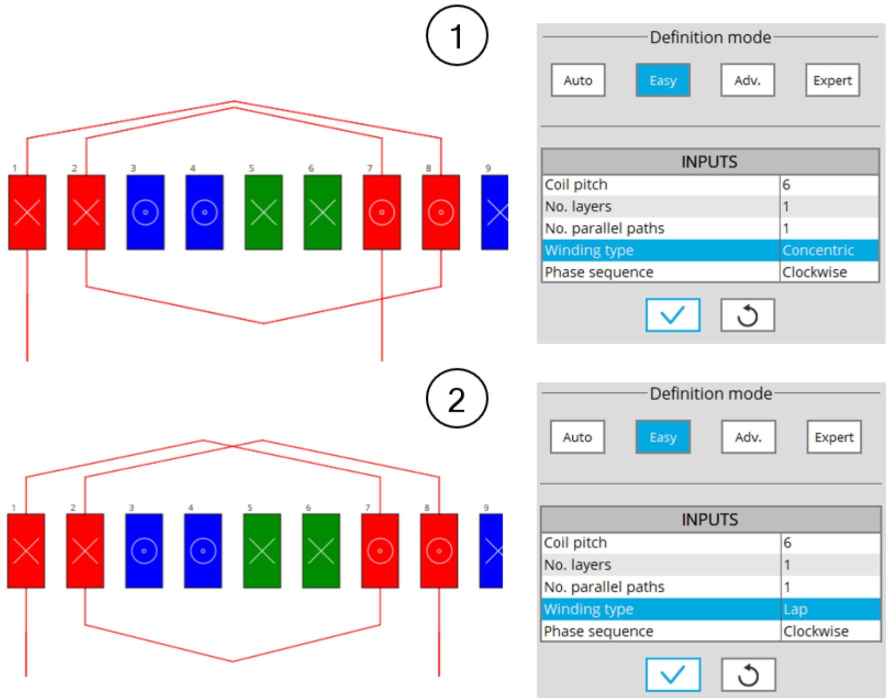
Building the winding architecture – The number of layers are represented in the winding scheme	
1	Example, where the No. layers is equal to 1.
2	Example, where the No. layers is equal to 2.

2.2.3.4 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).

2.2.3.5 Winding type



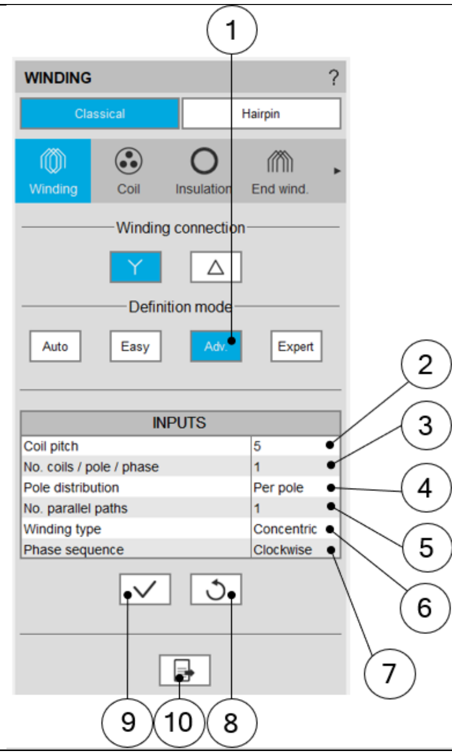
Building the winding architecture – Definition of the winding type: Lap or Concentric	
1	Example for the **Concentric** winding type.
2	Example for the **Lap** winding type.

2.2.4 Advanced mode

2.2.4.1 User input parameters

Label	Symbol	Tooltip, note, formula
Coil pitch	*	Coil pitch = number of slot pitch between coil input and coil output (Easy mode / Advanced mode).
Winding type	*	Winding type - Lap or Concentric (Easy mode / Advanced mode).
Pole distribution	*	Pole distribution – Per pole or Consequent (Advanced mode).
No. coils / pole / phase	CPP	Number of coils per pole and per phase (Advanced mode).
Phase sequence	*	Phase sequence (all modes).
No. parallel paths	P_{paths}	Number of parallel paths (all modes).

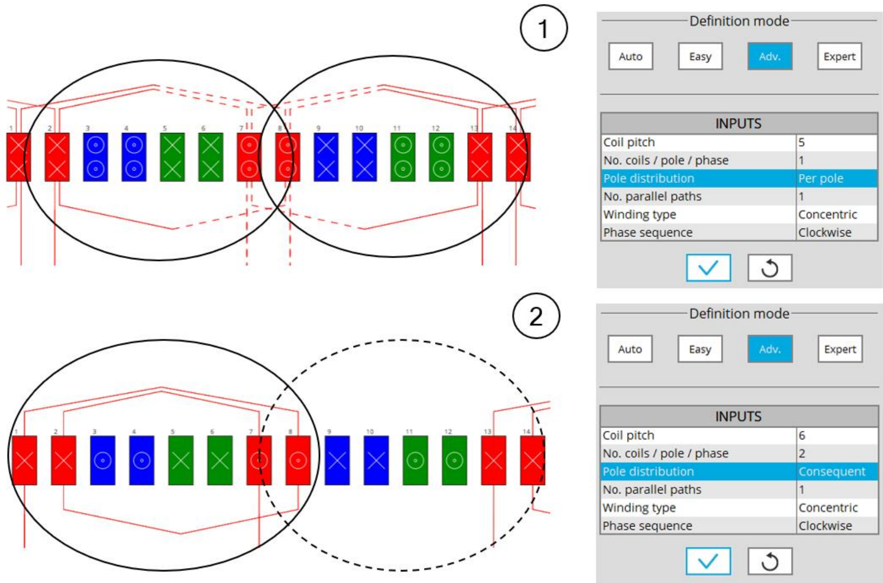
2.2.4.2 Building the winding architecture – Advanced mode – Main principles



Building the winding architecture - **Advanced** mode

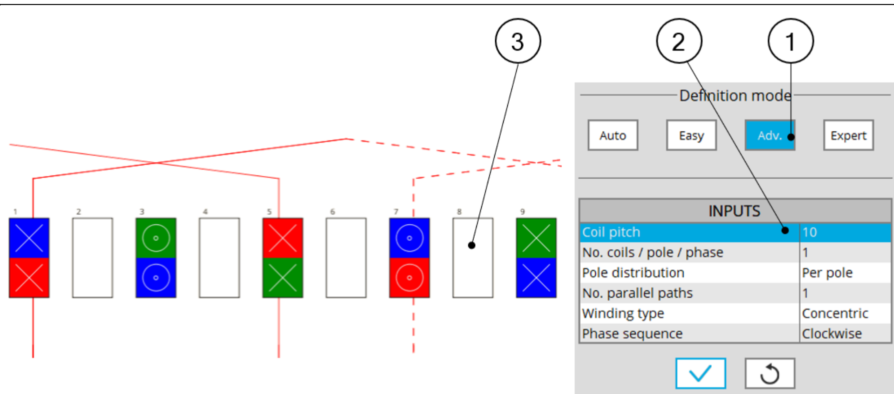
1	Selection of the **Advanced** mode for building the winding architecture.
2	Selection of coil pitch. In advanced mode, the user must define this value. There is no proposed short list of solutions. The relevance of the winding architecture has to be verified by the user.
3	Definition of the number of coils per pole and per phase.
4	Definition of the pole distribution: Per pole or Consequent. See an illustration of the two-pole distribution below.
5	Number of parallel paths. 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. See examples in Auto mode chapter.
6	Selection of winding type: Concentric or Lap. Illustration of these two types of winding is given in the Easy mode section.
7	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 the machine facing is towards the connection side
8	Icon to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
9	Icon to apply inputs. Pressing the enter key twice applies inputs too.
10	Icon to export winding data into a text file

2.2.4.3 Pole distribution



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.

2.2.4.4 Winding customization



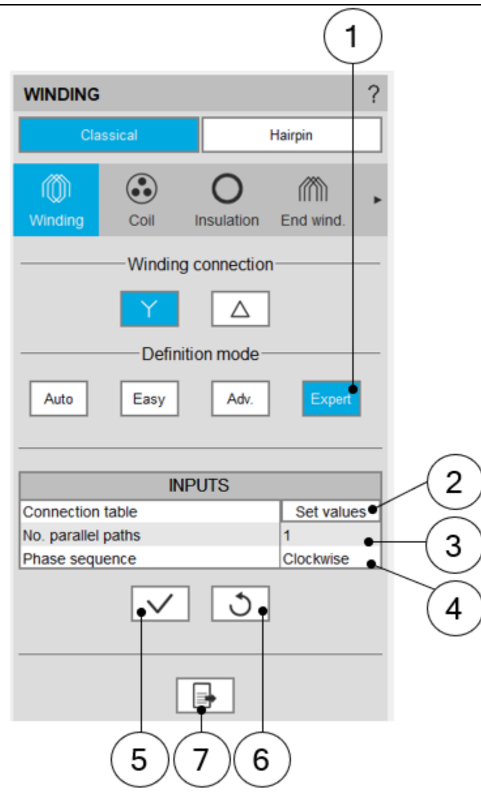
Building the winding architecture – Advanced mode The relevance of the winding architecture must be verified by the user	
1	Selection of the **Advanced** mode for building the winding architecture.
2	The choice of the user is not limited by a list. Any integer value can be chosen for the Coil pitch. For example in this case, 10 has been written.
3	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**: The process allows only zero, one or two coils per slot.

2.2.5 Expert mode

2.2.5.1 User input parameters

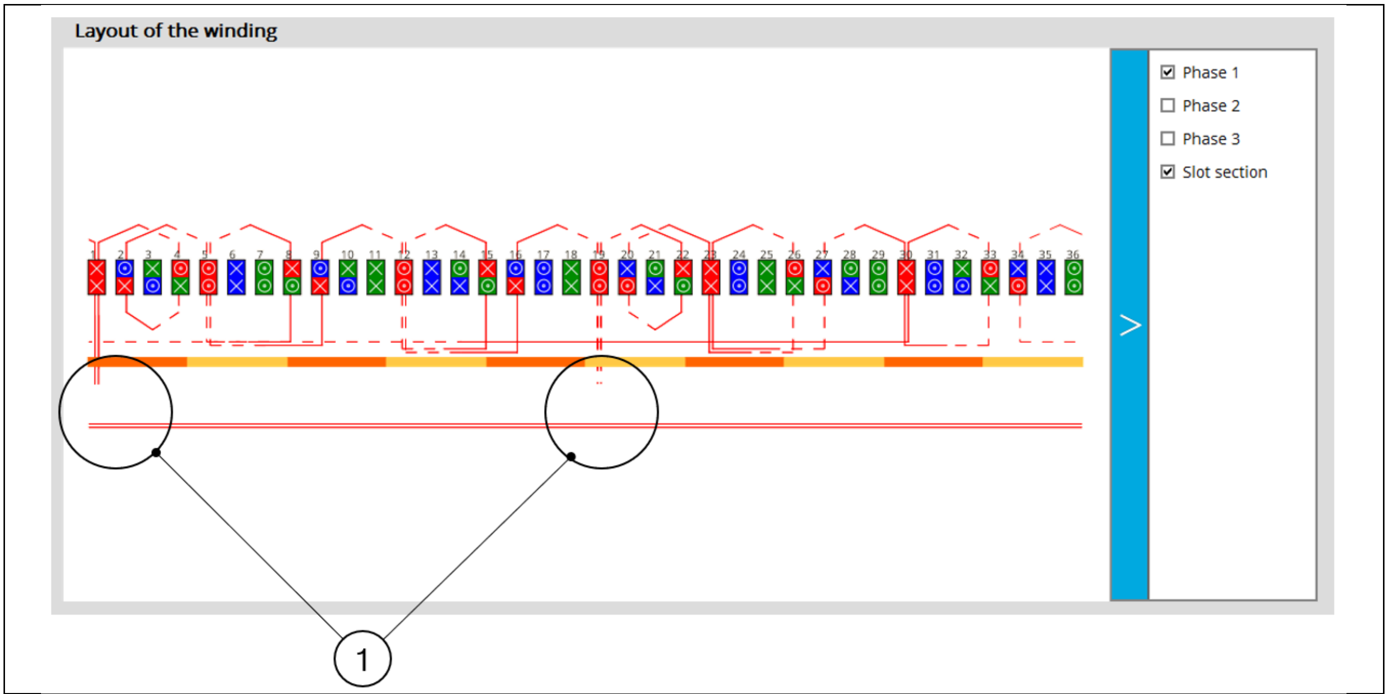
Label	Symbol	Tooltip, note, formula
No. Layers	N_{Layers}	Number of layers - 1 or 2 (Easy mode).
Coil layout	*	Coil layout inside the slot – Full, Superimposed or Adjacent (Advanced mode).
No. duplications	*	Number of duplications (Advanced mode).
Phase sequence	*	Phase sequence (all modes).
No. parallel paths	P_{paths}	Number of parallel paths (all modes).

2.2.5.2 Main principles



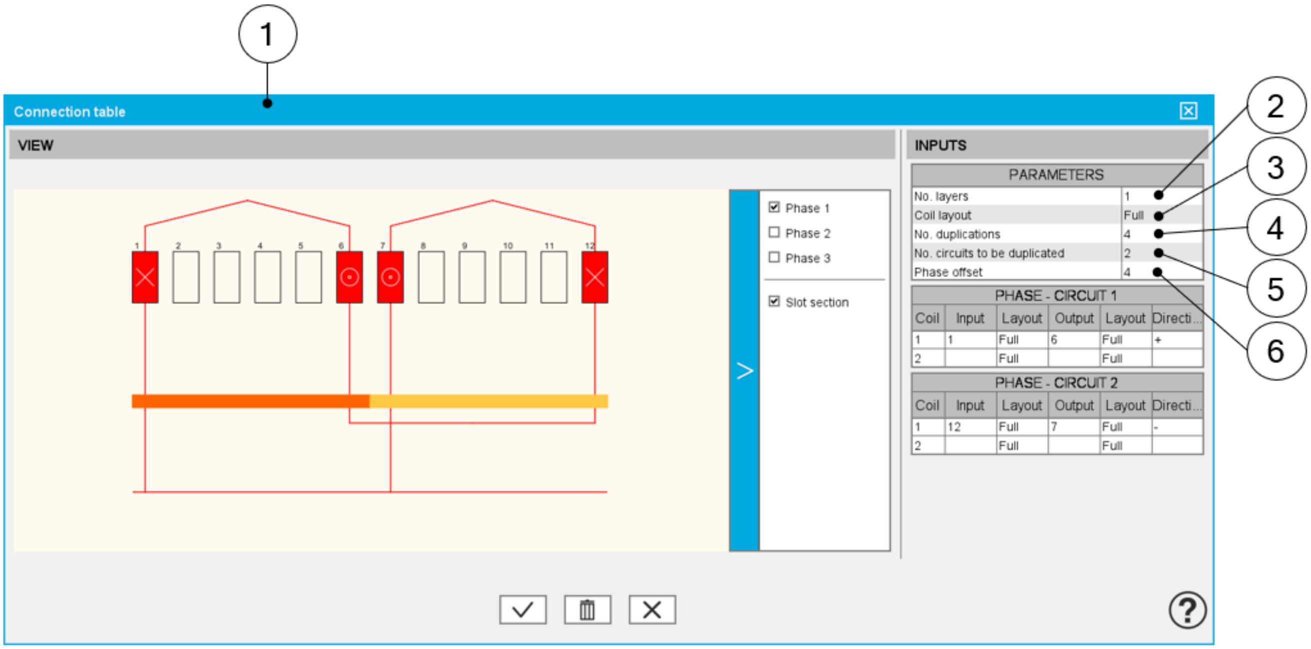
Building the winding architecture - **Expert** mode

1	Selection of the **Expert** mode for building the winding architecture.
2	“Set values” means opening the dialog box to fill the connection table. See illustration below.
3	Number of parallel paths. 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. 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. See the illustration below.
4	Definition of the phase sequence i.e. the rotation direction of the Magneto-Motive Force (M.M.F): Clockwise or Counter clockwise.
5	Icon to apply inputs. Pressing the enter key twice applies inputs too.
6	Icon to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
7	Icon to export winding data into a text file

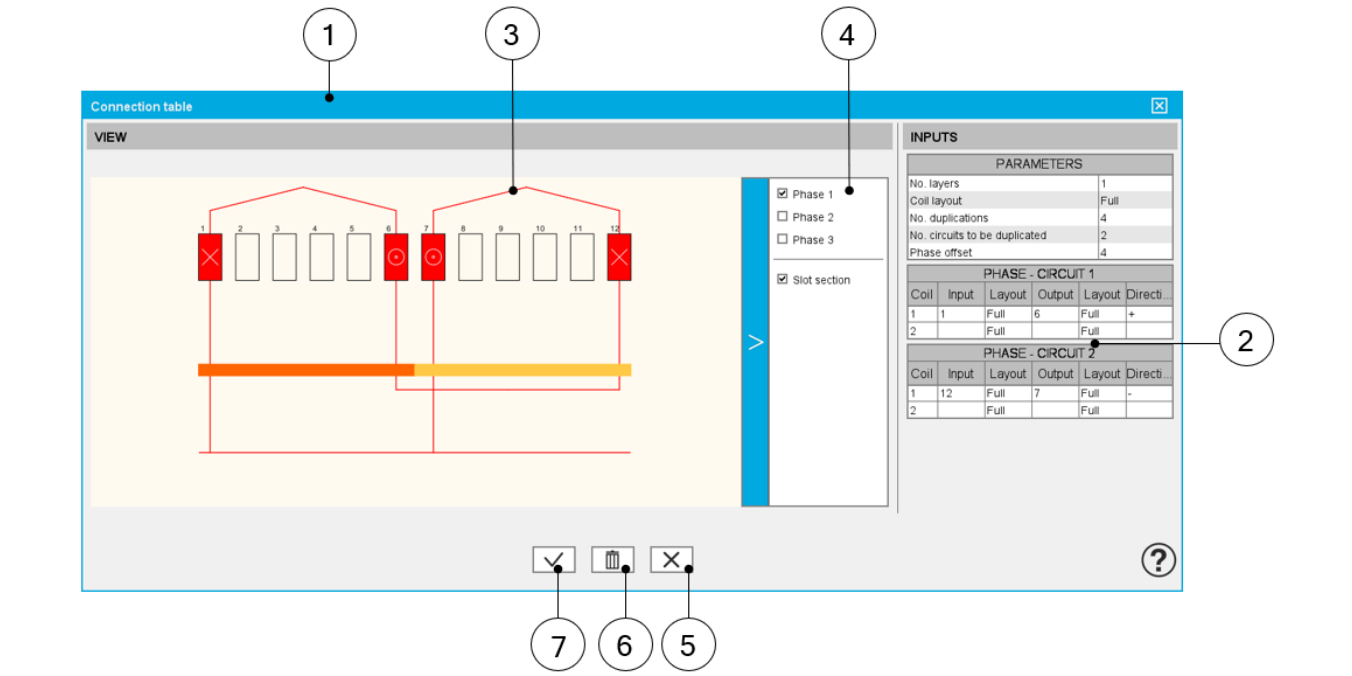


Case where the connection of the parallel paths is not displayed

2.2.5.3 Build a coil with expert mode



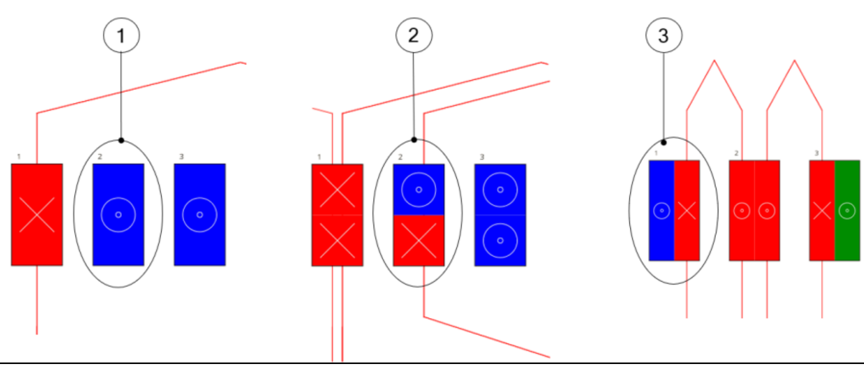
	Building the winding architecture – Filling of the connection table
1	Dialog box to define a coil with Expert mode
2	Selection of the number of layers. The solutions depend on the number of slots and the number of poles. Example: With 12 slots and 10 poles, only one solution is proposed: 1 layer. The three possible cases are illustrated in the Easy mode section.
3	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 slots and the number of poles. Example 1: With 12 slots and 10 poles, 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 and 8 poles, one solution is imposed: Full.
4	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.
5	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
6	Phase offset – See illustration below.



Building the winding architecture – Filling of the connection table

1	Dialog box to define a coil with expert mode
2	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.
3	Display of the 3-Phase winding
4	Make the phase visible or not
5	Button to cancel action and close the panel.
6	Button for erasing everything in the connection table (*Erase connection table data*).
7	Button to apply inputs and close the panel.

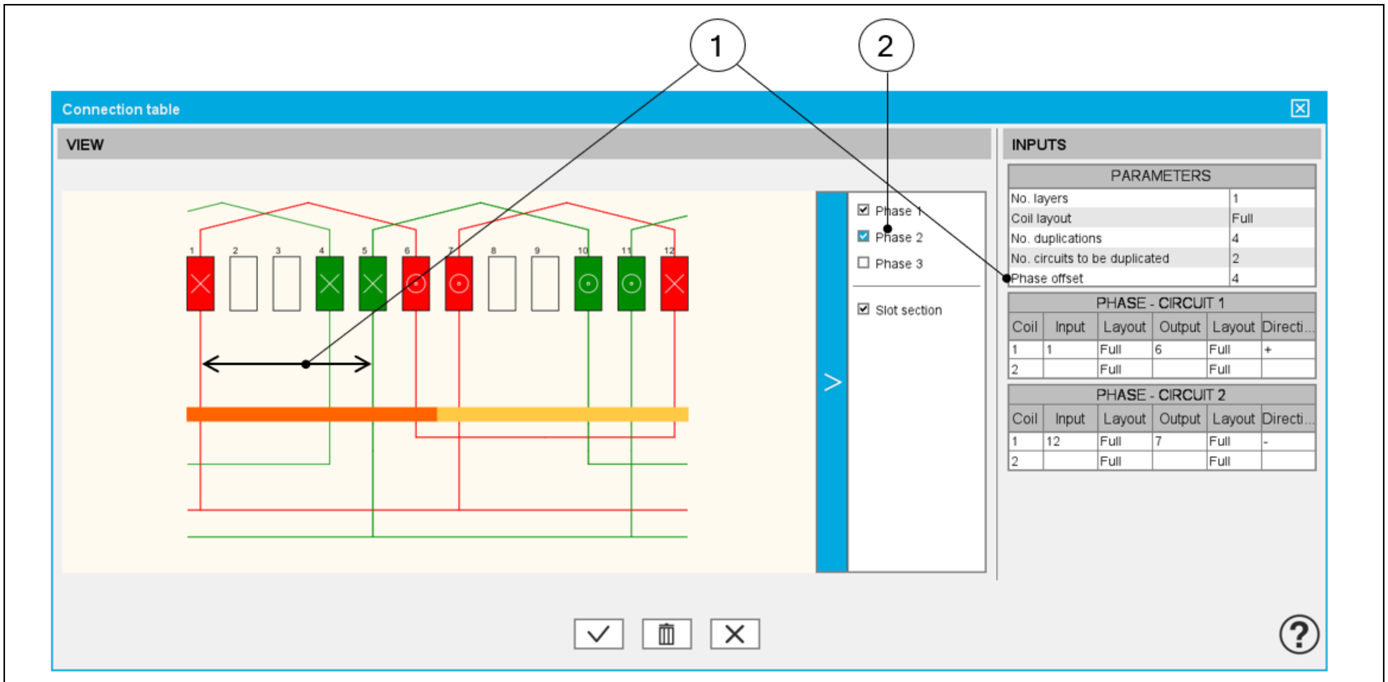
2.2.5.4 Coil layout in slot



Building the winding architecture – Definition of coil layout

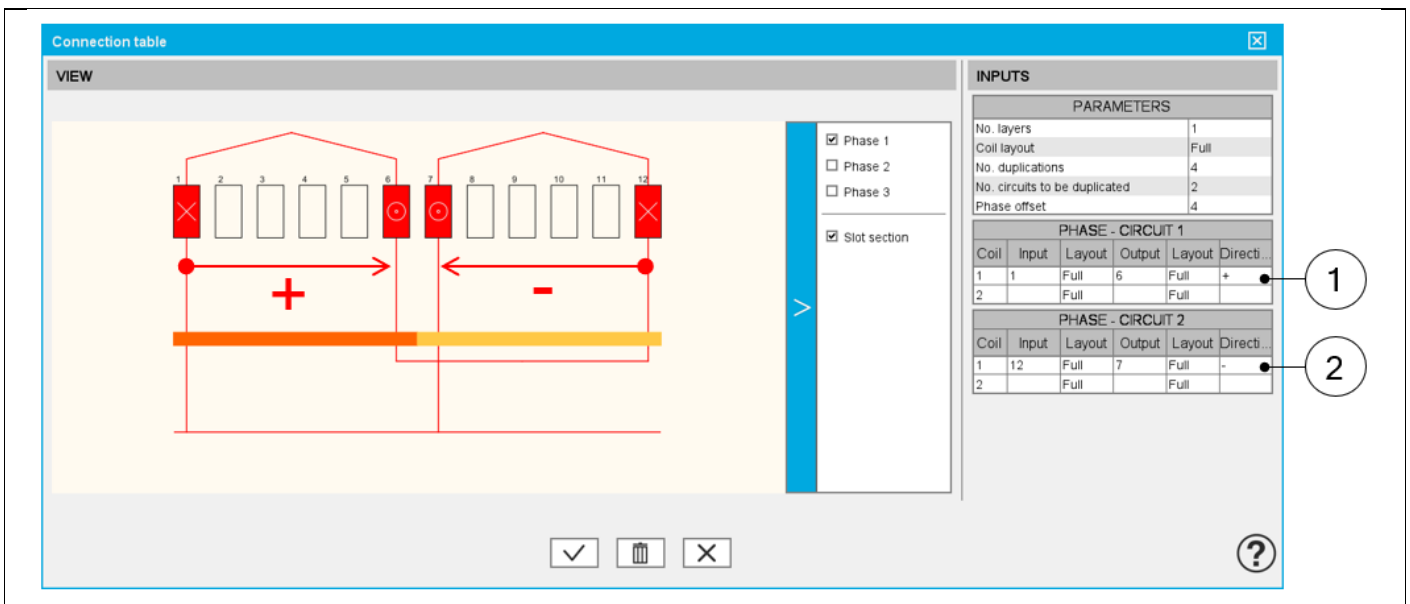
1	Example where the coil layout is **Full**.
2	Example where the coil layout is **Superimposed**.
3	Example where the coil layout is **Adjacent**.

2.2.5.5 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.

2.2.5.6 Winding direction for coils

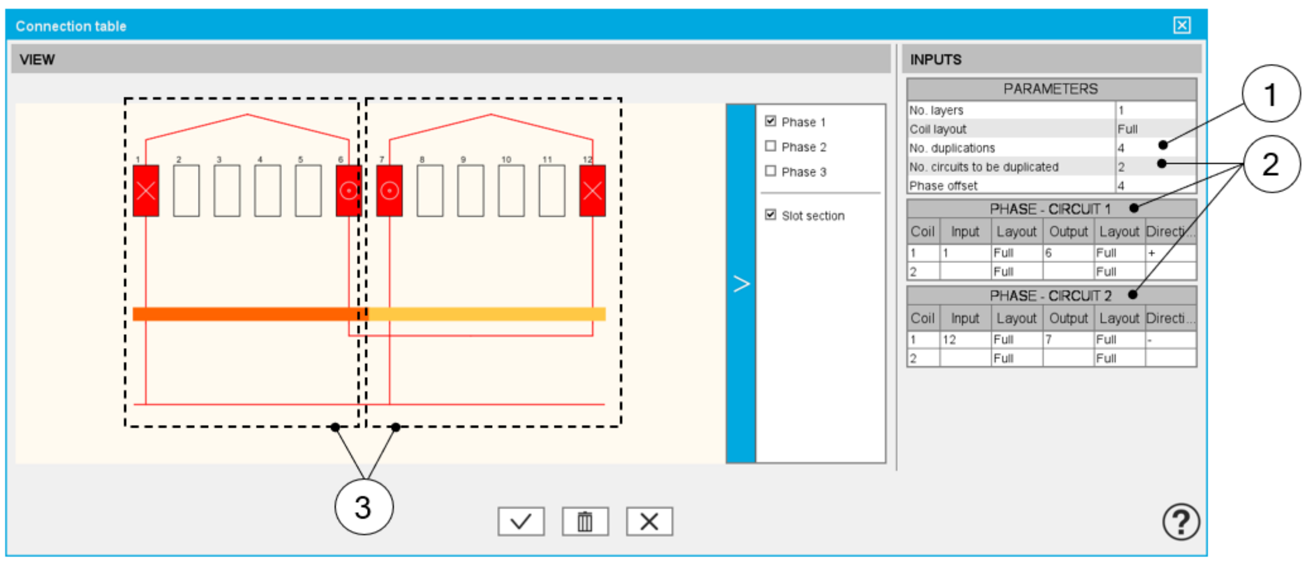


Orient the coils when defining the phase circuits	
1	Definition of a positive orientation of coil i.e., in the clockwise direction from the connection size (=ascending order of slot numbers)
2	Definition of a negative orientation of coil i.e., in the counterclockwise direction from the connection size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

2.2.5.7 Additional information

The real distribution of the parallel paths in the winding is taken into account for performing the tests. It wasn't the case informer versions. Hence, it wasn't possible to know how the parallel paths are distributed and sometimes this led to a error. This issue has been fixed.

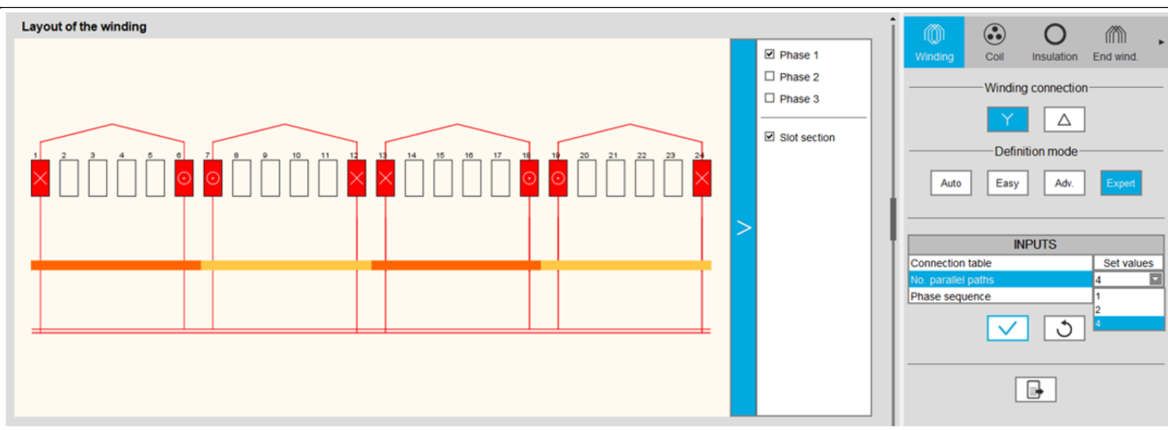
From now on, one need to know how the parallel paths were distributed. To do that, in the expert mode, to define the connection table, the user can define the number of circuits to be duplicated and for that, he must fill in a connection table for each elementary parallel path.



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.



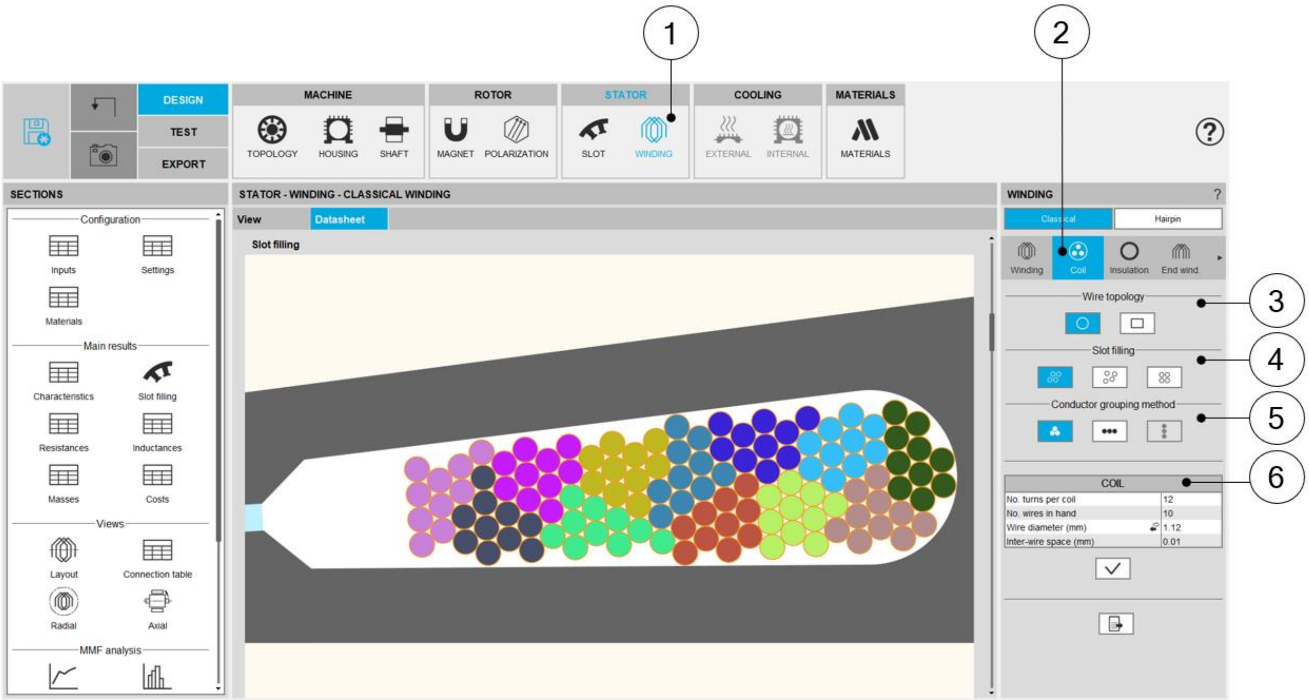
Layout of the resulting winding architecture

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.

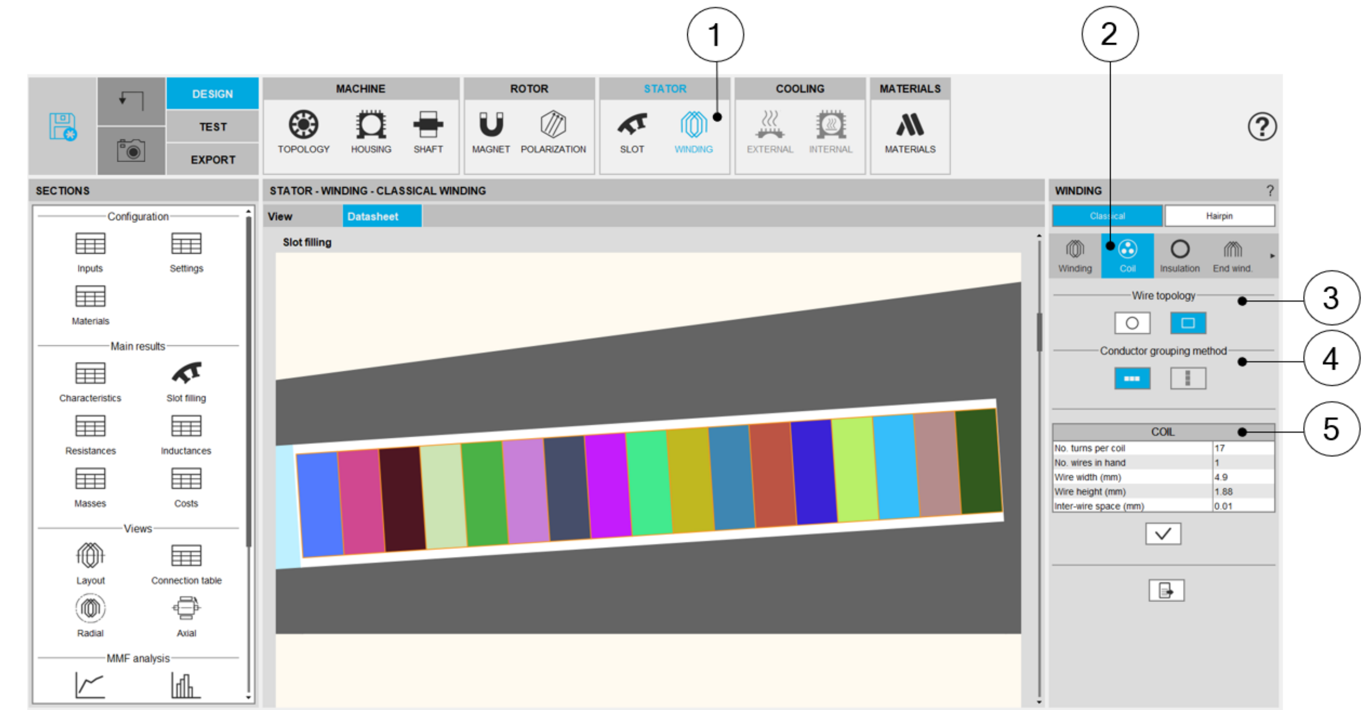
Important note: This modification is a problem for motors the number of parallel paths « No. parallel paths » of which is greater to the number of duplications « No. duplications »
In that case, one has decided to modify the value of the « No. parallel paths » to make it take the value of the « No. duplications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

2.3 Classical coil design - Inputs

2.3.1 Overview - Definitions



Definition of the coil – Case of Circular wires	
1	Selection of the STATOR subset: WINDING panel (Click on the icon WINDING)
2	Coil settings allows the user to describe the coil composition (turns, wires, dimensions) and how to fill the slot.
3	Definition of the wire topology, Circular or Rectangular
4	Choice of the method to fill the slot: Three ways are allowed to fill the slot: Orthocyclic, Random, Layer. See below illustrations.
5	Choice of the method to group the elementary wires. Three ways allow to fill the slot: Grouped, Horizontal, Vertical. See below illustrations.
6	Description of the coil (turns, wires in hand) and dimensions of elementary wires



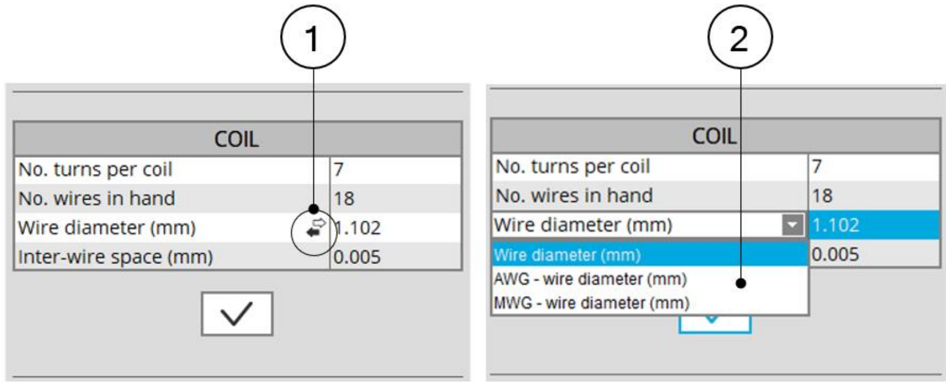
Definition of the coil – Case of rectangular wires	
1	Selection of the STATOR subset: WINDING panel (Click on the icon WINDING)
2	Coil settings allows the user to describe the coil composition (turns, wires, dimensions) and how to fill the slot.
3	Definition of the wire topology, Circular or Rectangular
4	Choice of the method to group the elementary wires. Three ways allow to fill the slot: Horizontal, Vertical. See below illustrations.
5	Description of the coil (turns, wires in hand) and dimensions of elementary wires

The following inputs define the coil and how is filled the slots

Label	**Symbol**	**Tooltip, note, formula**
Wire topology	*	Wire topology, Circular or Rectangular.
Slot filling	*	Three ways are allowed to fill the slot: Orthocyclic, Random, Layer See below illustrations
Conductor grouping method	*	Three ways are allowed to fill the slot: Grouped, Horizontal, Vertical See below illustrations
No. turns per coil	Turns	Number of turns per coil.
No. wires in hand	Nwires	Number of wires in parallel in a conductor (per turn) i.e. number of wires in parallel in each conductor.
Wire diameter	$\emptyset_{wire}$	Wire diameter (without insulation), for circular wire (1)
Wire width	W_{wire}	Wire width (without insulation), for rectangular shape type wire
Wire height	H_{wire}	Wire height (without insulation), for rectangular shape type wire
Inter-wire space	w/w	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).

(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)



1	Multiple choices with a scrolling selection bar for selecting the wire diameter
2	Three ways are available for defining the dimensions of the wire diameter: • Write the value of the wire diameter or to select it from the two below tables: • American Wire Gauge table in which available wire diameters are listed (without insulation) • Metric Wire Gauge table in which available wire diameters are listed (without insulation)

(2) Illustration of inter-wire space

This value is considered in Motor factory for computing the filling factor, and also while exporting a model into Flux® environment (EXPORT area) for building the corresponding finite element model.

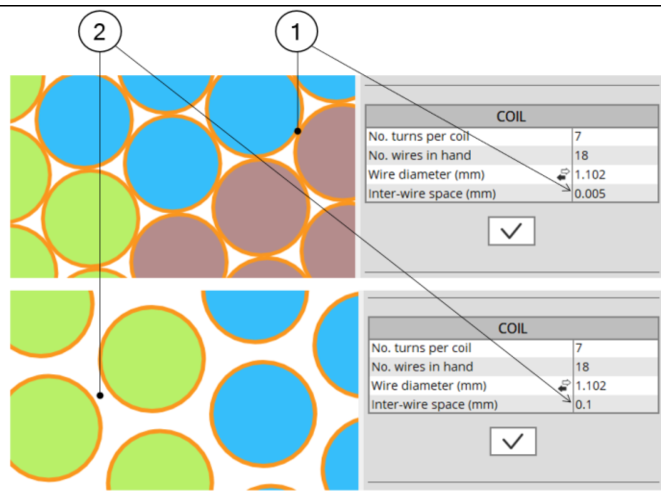
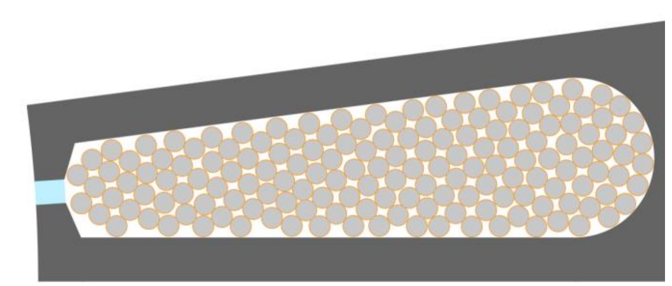
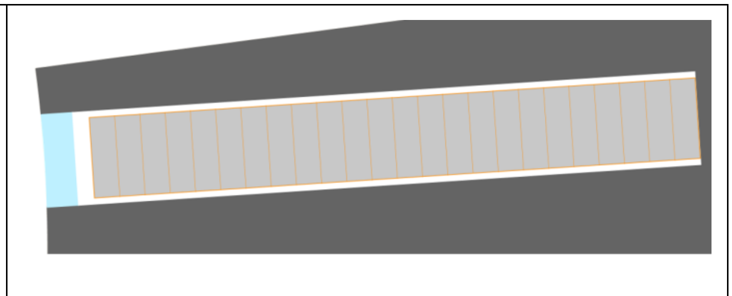


Illustration of inter-wire space

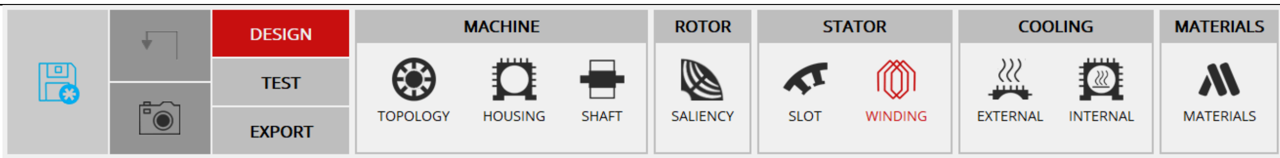
1	Default value for inter-wire space and the corresponding pictorial display.
2	Impact of a higher value for inter-wire space

2.3.2 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 shape type wire	Grayed rectangular shape type wire

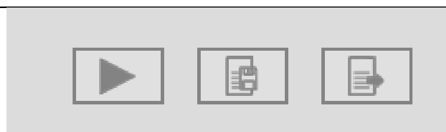
Motor Factory Design environment icon and winding icon in the Stator section are colored in red. This means that a design fault exists, and must be corrected in the winding section of the design environment.



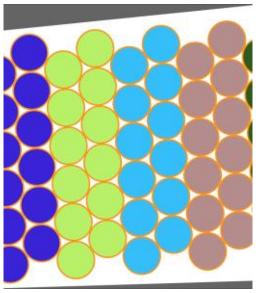
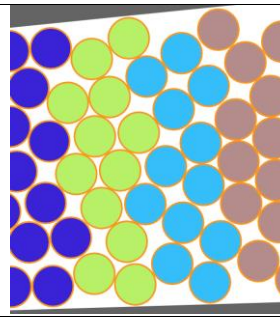
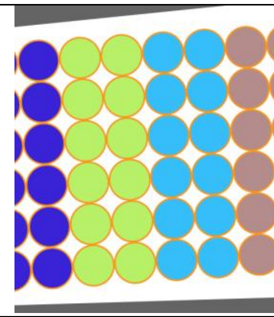
Motor Factory Design environment Icon and the winding icon in the Stator section are colored in red.
= a design fault must be corrected

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.

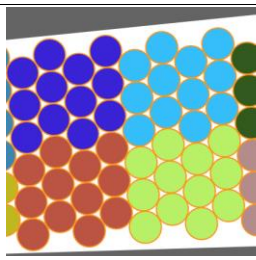
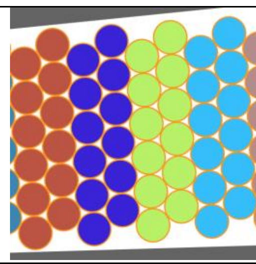
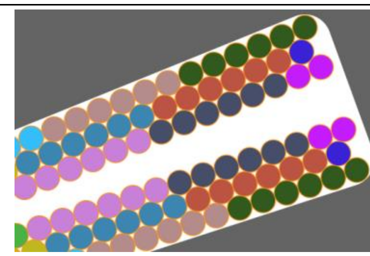

The tests cannot be performed

2.3.3 Slot filling illustrations – Circular shape type wire

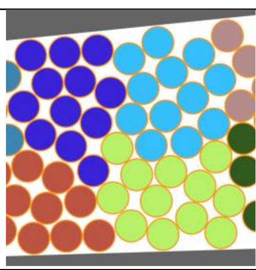
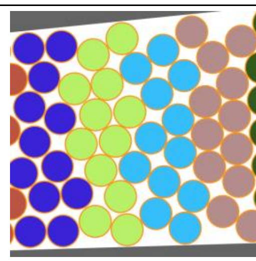
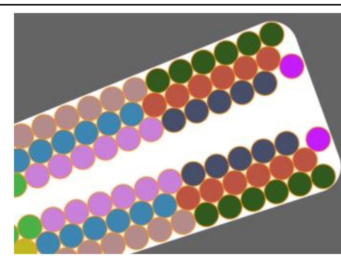
		
Orthocyclic slot filling	Random slot filling	Layer slot filling

2.3.4 Conductor grouping method illustrations - Circular shape type wire

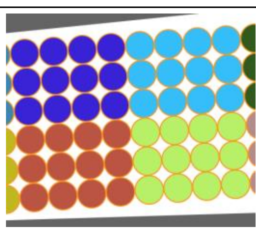
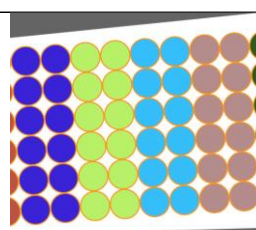
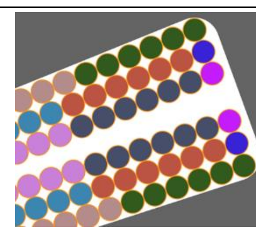
Case 1 – With an Orthocyclic slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

Case 2 – With a random slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

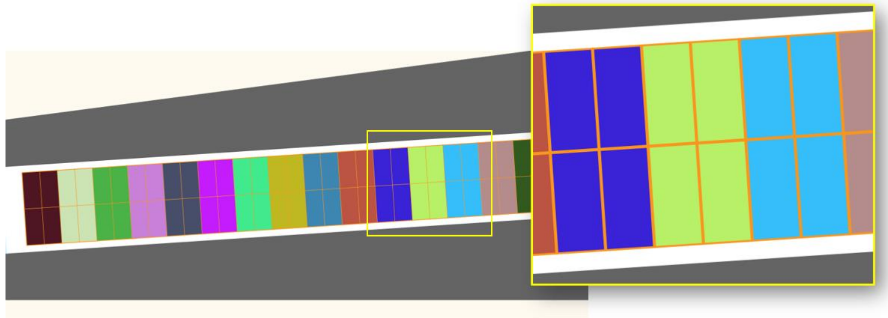
Case 3 – With a layer slot filling

		
Grouped filling	Horizontal filling	Vertical filling (1)

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

2.3.5 Conductor grouping method illustrations - Rectangular shape type wire

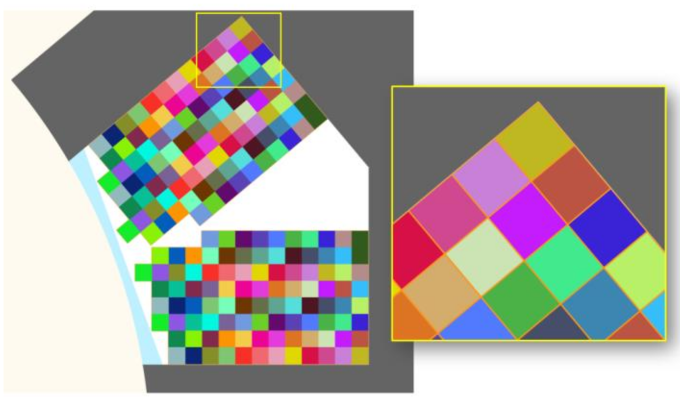
Example 1



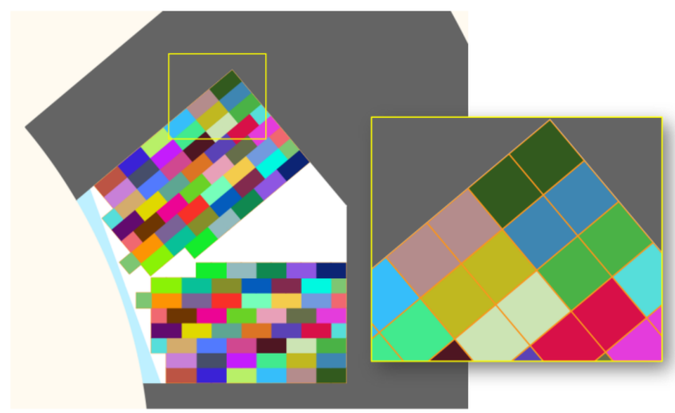
Horizontal filling

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)

2.4 Winding insulation design - Inputs

2.4.1 Overview - Definitions

Here are all the available insulation types.

Label	Symbol	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)

2.4.2 Illustrations for circular shape type wire

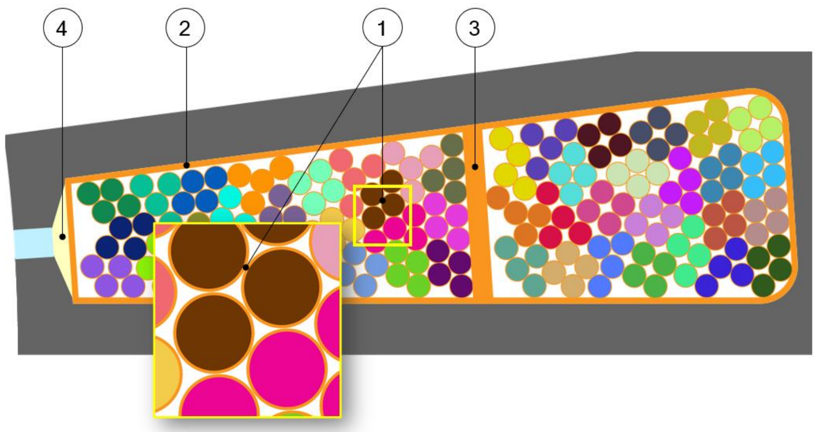


Illustration of winding insulation for circular shape type wire

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 Impregnation

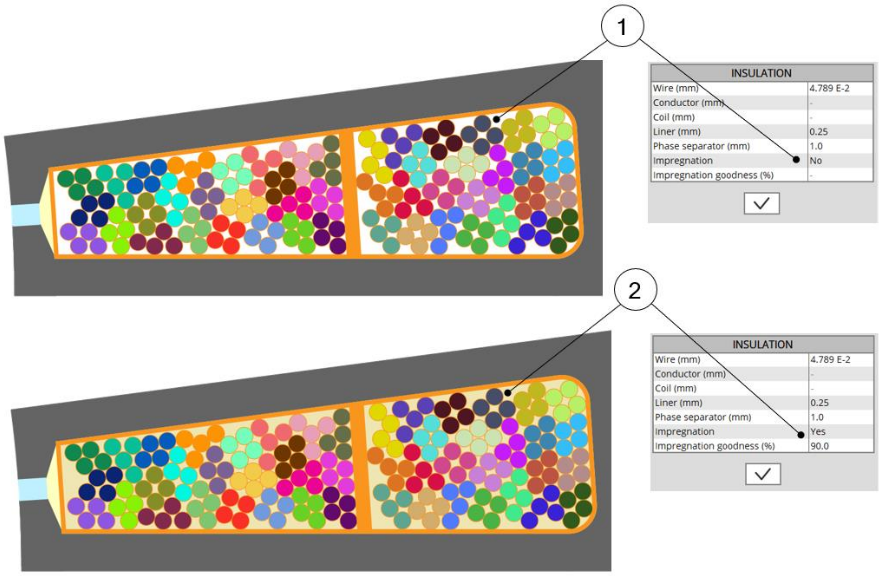


	Illustration of winding impregnation in slot
1	Winding without impregnation. The surface of the slot's free area is white.
2	Winding with impregnation. The free area of the slot is colored (light yellow). The impregnation goodness is defined by indicating the ratio between the volumes of impregnation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

2.4.4 Illustrations for rectangular shape type wire

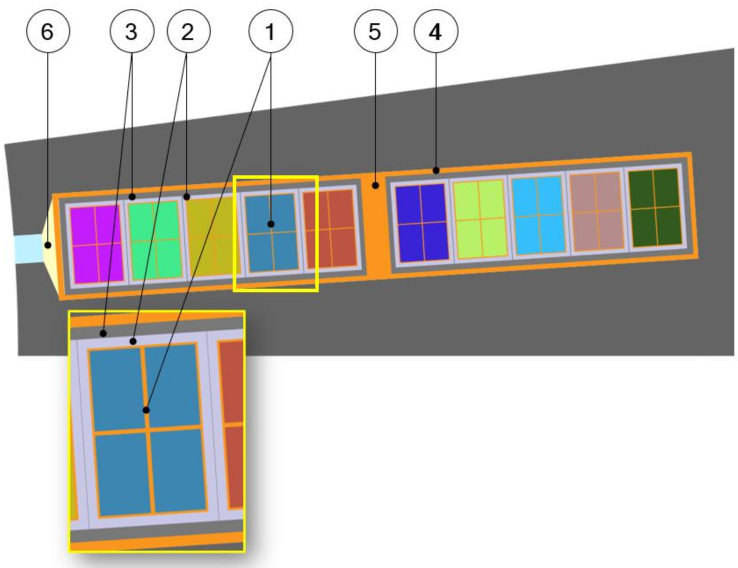


	Illustration of winding insulation for rectangular shape type wire
1	Insulation thickness of the wire
2	Insulation of conductors. This is available only for rectangular shape type wire when the conductor (i.e. the elementary group of wires in hand) has a rectangular outer shape.
3	Insulation of coils. 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.

2.5 End winding design of classical winding – Inputs

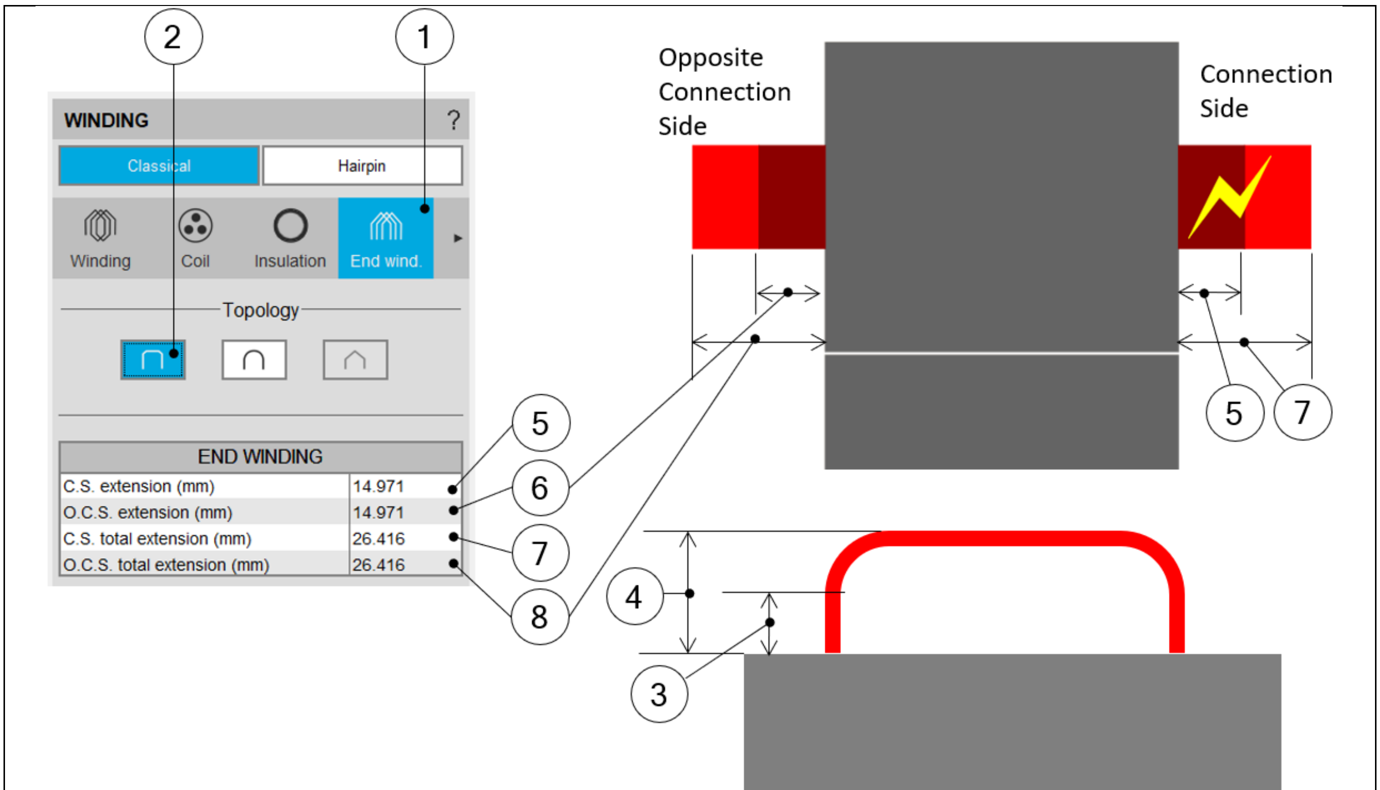
2.5.1 Overview - definitions

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	Symbol	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 End-winding topology – U-Shape

Topology available for all the 3 winding architectures

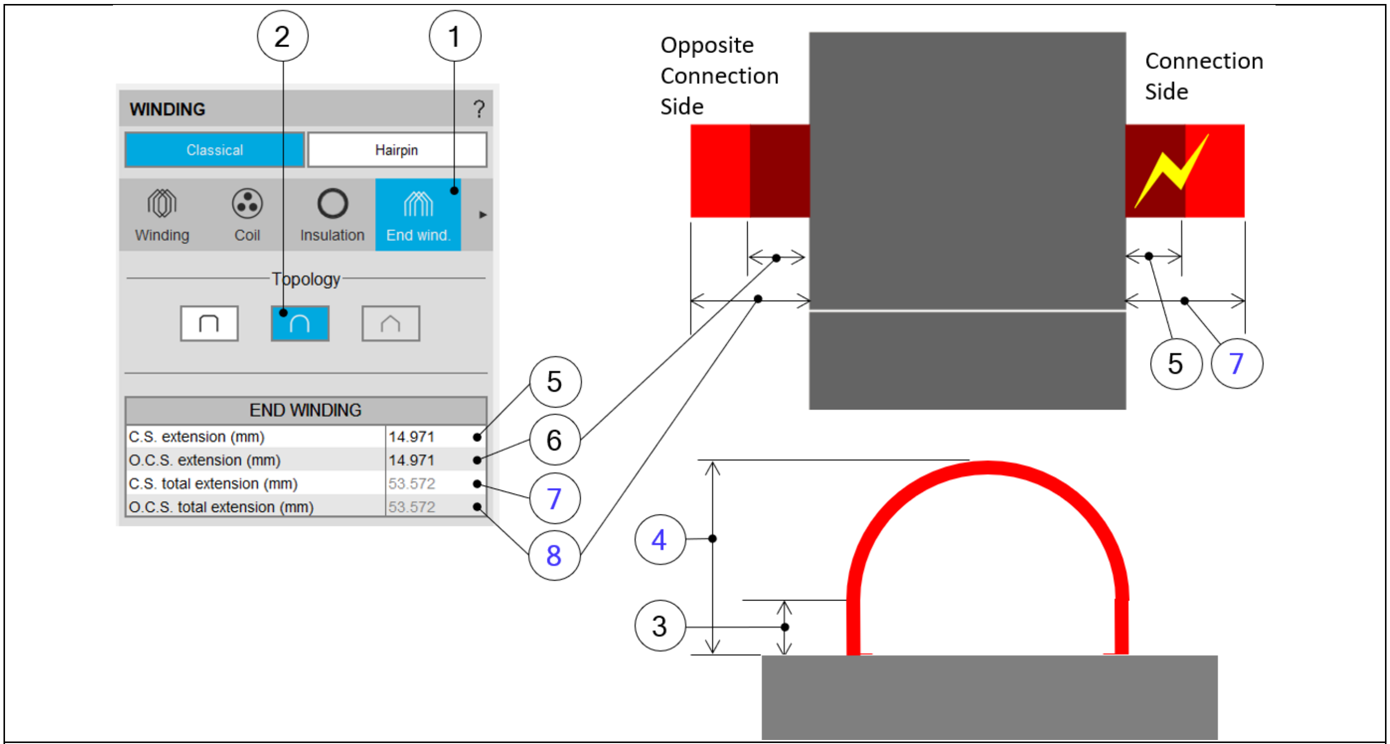


Building the winding – End-winding topology and dimensions
Case of the U-shape End-winding

1	Selection of the **END-WINDING** tab.
2	Selection of the U-Shape end-winding case.
3	Straight extension of the U-Shape end-winding topology = User input parameter.
4	Total extension of the U-Shape end-winding topology = User input parameter.
5	Definition of the connection side straight extension (ref. 3).
6	Definition of the opposite connection straight extension (ref. 3).
7	Definition of the connection side total extension (ref. 4).
8	Definition of the opposite connection side total extension (ref. 4).

2.5.3 End-winding topology – C shape

Topologies available for all winding architecture

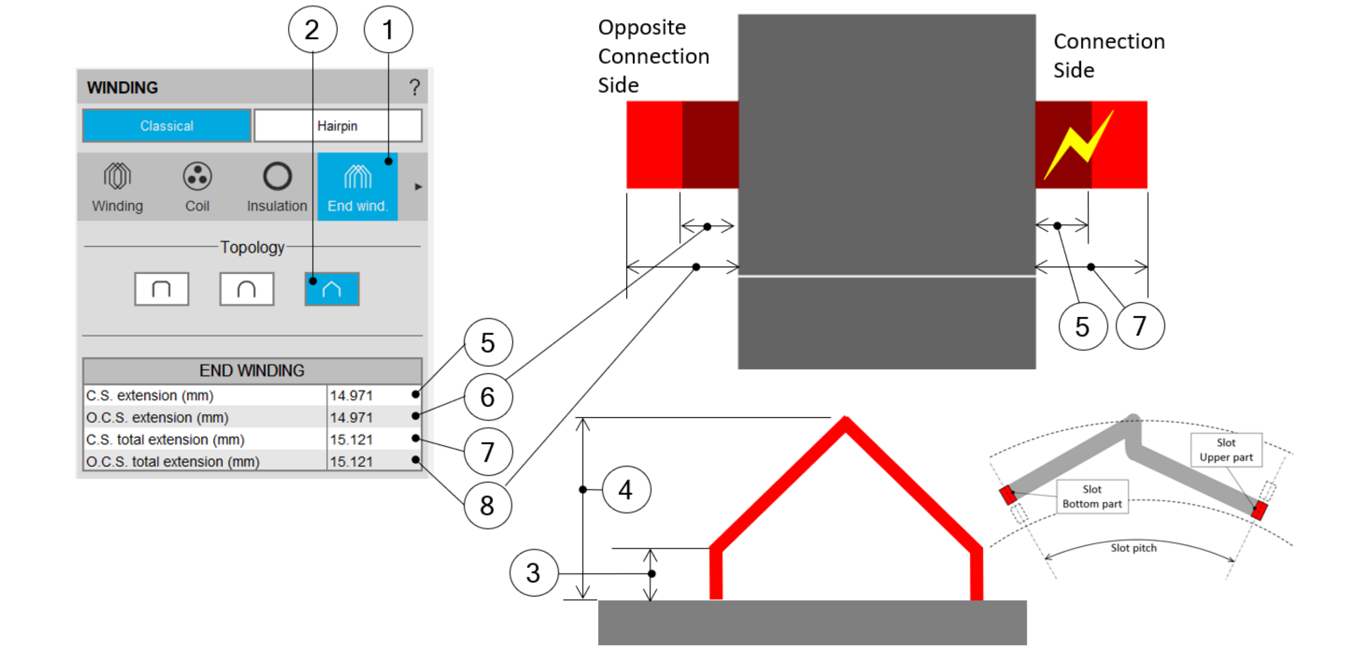


Building the winding – End-winding topology and dimensions
Case of the C-shape End-winding

1	Selection of the **END-WINDING** tab.
2	Selection of the C-Shape end-winding topology.
3	Straight extension of the C-Shape end-winding topology = User input parameter.
4	Total extension of the C-Shape end-winding topology = Computation result deduced from topology characteristics.
5	Definition of the connection side straight extension = User input (ref. 3).
6	Definition of the opposite connection straight extension = User input (ref. 3).
7	Definition of the connection side total extension = Deduced result (ref. 4).
8	Definition of the opposite connection side total extension = Deduced result (ref. 4).

2.5.4 End-winding topology – Y shape

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



Building the winding – End-winding topology and dimensions
Case of the Y-shape End-winding

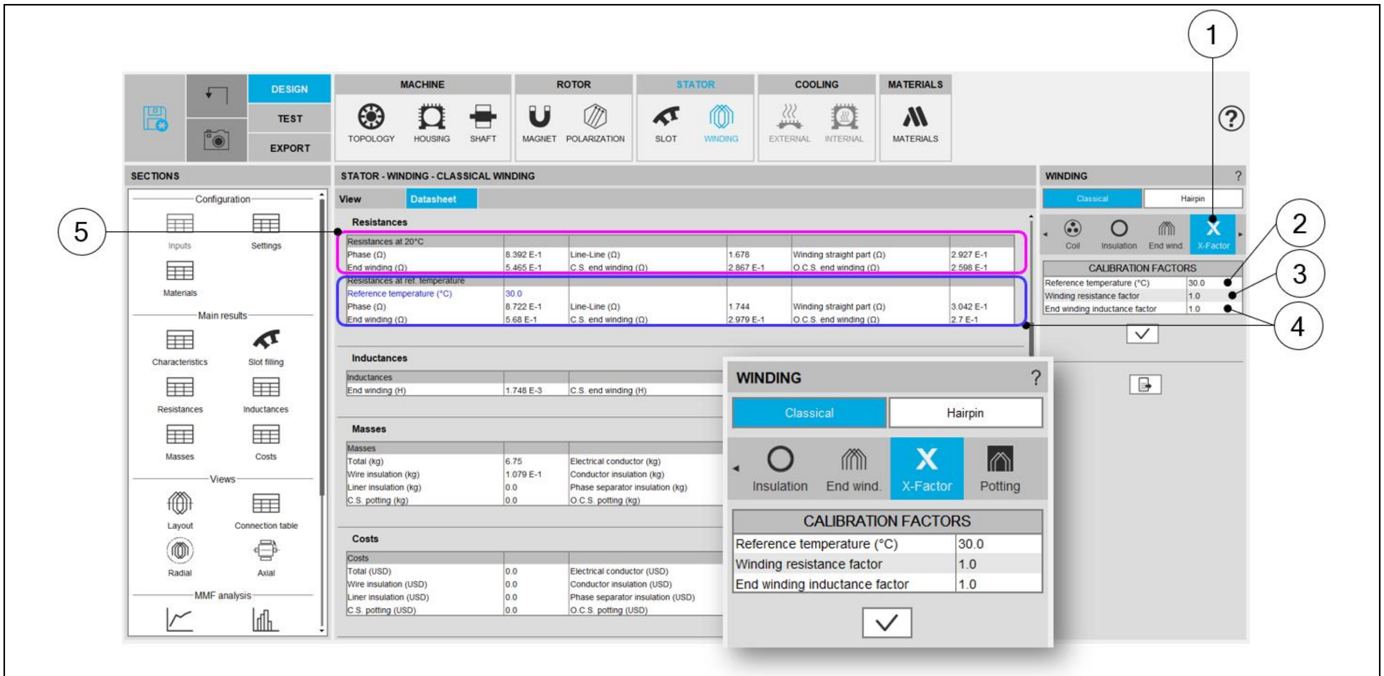
1	Selection of the **END-WINDING** tab.
2	Selection of the Y-Shape end-winding case.
3	Straight extension of the Y-Shape end-winding topology = User input parameter.
4	Total extension of the Y-Shape end-winding topology = User input parameter.
5	Definition of the connection side straight extension (ref. 3).
6	Definition of the opposite connection straight extension (ref. 3).
7	Definition of the connection side total extension (ref. 4).
8	Definition of the opposite connection side total extension (ref. 4).

2.6 Calibration factors (Definition – Inputs)

2.6.1 Overview - Definitions

Label	Symbol	Tooltip, note, formula
Resistance factor	*	Setting of the “Resistance factor”: It allows modifying the computation result of resistance. Thus, the resulting phase resistance value is considered.
Inductance factor	*	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.
Ref. temperature	*	The reference temperature: First, the 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).

2.6.2 Illustrations

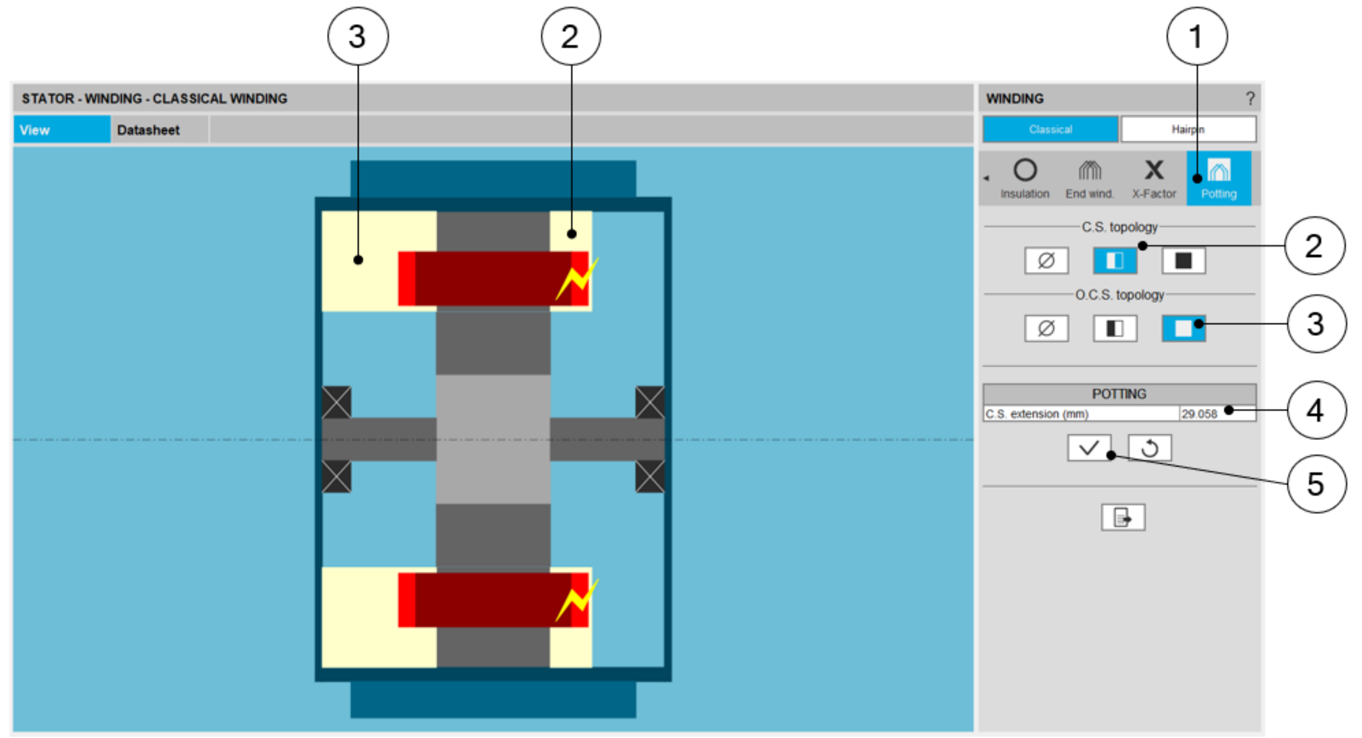


Building the winding – X-Factor = Calibration factors	
1	Selection of the **X-FACTOR** section.
2	Setting of the “Resistance factor”. It allows adjusting computation result of resistance. Thus, the resulting phase resistance value is considered.
3	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.
4	The reference temperature: First, resistance values are computed by considering a temperature equal to 20°C (5). However, the users can also define their own reference temperature to compute the corresponding phase resistance and Line-Line resistance values.
5	Resistance values for a reference temperature equal to 20°C.

2.7 Potting design – Inputs

2.7.1 Overview - Definitions

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



Building the winding – Definition of the topology and dimensions of the potting around the end-winding	
1	Selection of the **Potting** section.
2	Button to define a potting with only radial contact.
3	Button to define a potting with radial and axial contacts.
4	Extension of potting with radial contact only.
5	Button to apply inputs. Apply is needed to modify the characteristics.

3 CLASSICAL WINDING OUTPUTS

3.1 Characteristics

3.1.1 Winding

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.
Coil layout	*	Coil layout inside the slot – Full, Superimposed or Adjacent.
Winding connection	Connect	Winding connection (Y – Wye or ∆ - Delta)
Winding type	*	The winding type: Lap, Concentric or manual. Note: “Manual” characterizes the “winding type” when the chosen “Winding mode” is “Expert mode”
Pole distribution	*	Pole distribution – “Per pole” or “Consequent” Accessible via “Advanced mode”.
No. slots / pole / phase	q	Number of slots per pole and per phase. $q = \frac{Nslots}{2p \times m}$ (p is the number of pole pairs and m the number of phases)
Pole pitch	τ_{pole-z}	$\tau_{pole-z} = \frac{No.slots}{2p}$ (Nslots = number of slots and p= 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.
No. coils / pole / phase	CPP	Number of coils per pole per phase (output data). As an output data, CPP is deduced from the analysis of the connection table. It is also a user input available in the advanced mode.
Coil pitch	τ_{coil}	Number of slot pitch between coil input and coil output (Easy mode and Advanced mode).

3.1.2 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.

3.1.3 Coil

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

3.1.4 Lengths

Label	Symbol	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.

3.1.5 Areas in slot

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

3.1.6 Fill factors

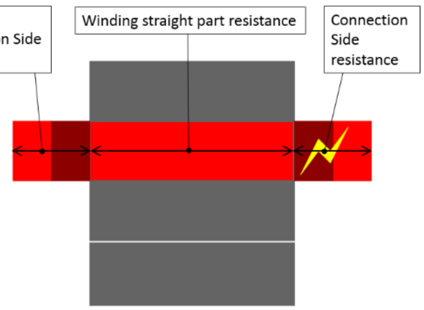
Label	Symbol	Tooltip, note, formula
Gross fill factor	*	Gross fill factor. Occupancy rate of the slot (conductive area only). $\frac{Conductor\ conductive\ area}{Slot\ area} \times 100$
Net fill factor	*	Net fill factor. Occupancy rate of the slot (conductive area + insulation area). $\frac{Conductor\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

3.2 Slot filling

The slot filling result gives the user a realistic view of the filling of the slot in function of the setting options. For additional information, please refer to the section 2.3 Classical coil design - Inputs.

3.3 Resistances

3.3.1 Resistances – Resistance at 20°C and at ref. temperature

<table>
<tr><th>Label</th><th>Symbol</th><th>Tooltip, note, formula</th></tr>
<tr><td>Phase resistance</td><td>*</td><td>Phase resistance</td></tr>
<tr><td>Line-Line resistance</td><td>*</td><td>Line-Line resistance</td></tr>
<tr><td>Winding straight part resistance</td><td>*</td><td rowspan="4">
</td></tr>
<tr><td>End-winding resistance</td><td>*</td></tr>
<tr><td>Connection side end-winding resistance</td><td>*</td></tr>
<tr><td>Opposite connection side end-winding resistance</td><td>*</td></tr>
</table>

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.

3.4 Inductances

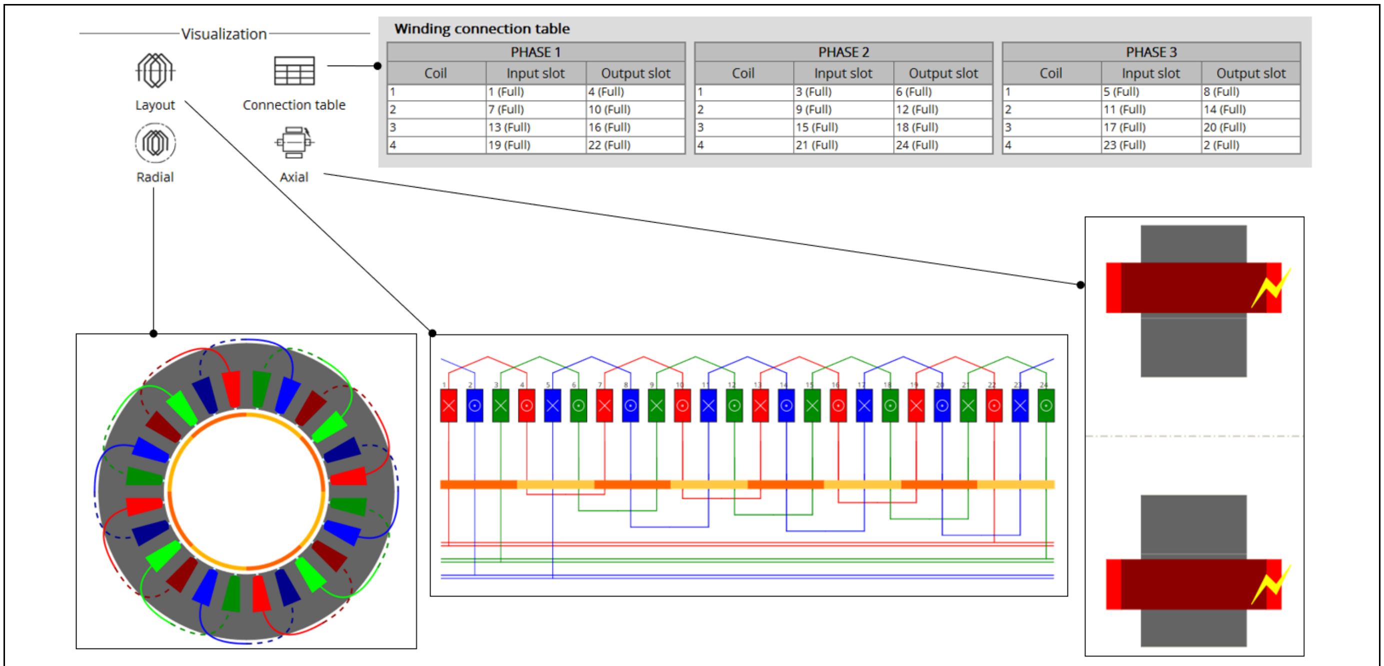
Label	Symbol	Tooltip, note, formula
End winding	*	Total end winding inductance (including the two sides of the machine).
C.S. end winding	*	Connection side end winding inductance.
O.C.S. end winding	*	Opposite connection side end winding inductance.

3.5 Masses and costs

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

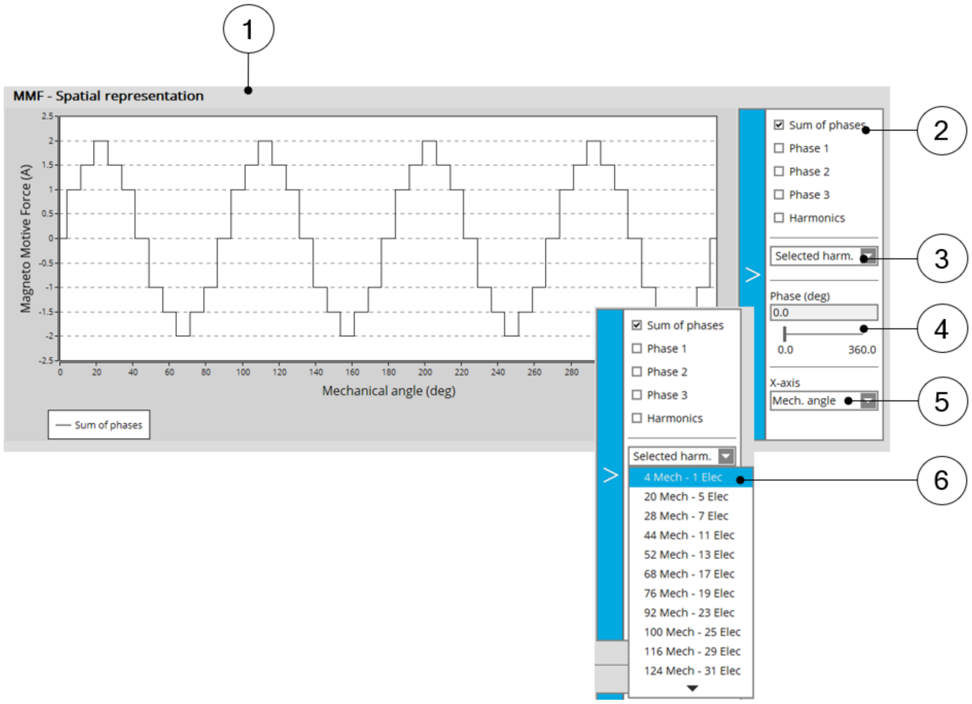
Label	Symbol	Tooltip, note, formula
Total	*	Total winding mass.
Electric conductor	*	Conductive part mass.
Total insulation	*	Total winding insulation mass (wire + conductor + coil insulation + liner + phase separator).
Wire insulation	*	Wire insulation.
Conductor insulation	*	Conductor insulation.
Coil 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

3.6 Visualization of the winding architecture

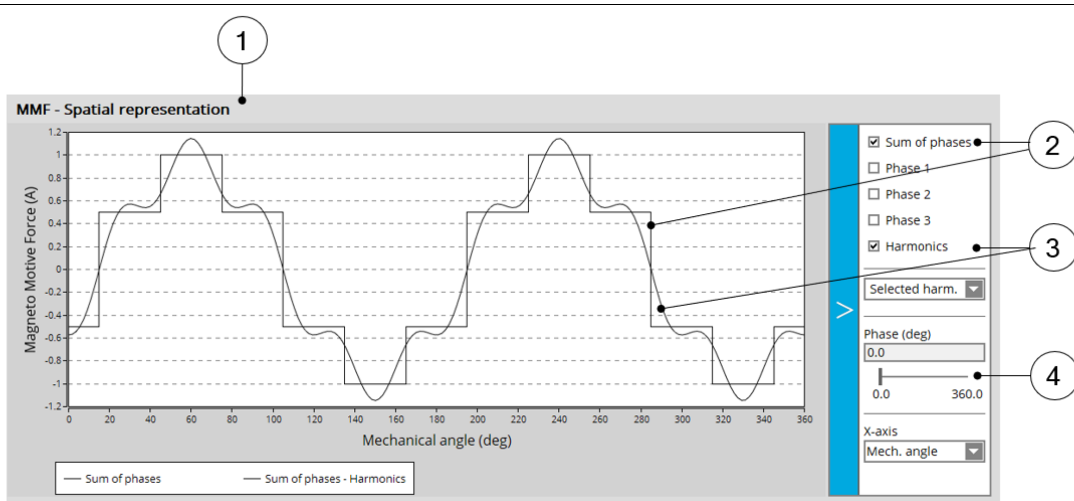


Visualization of the winding architecture

3.7 Magneto-Motive Force analysis



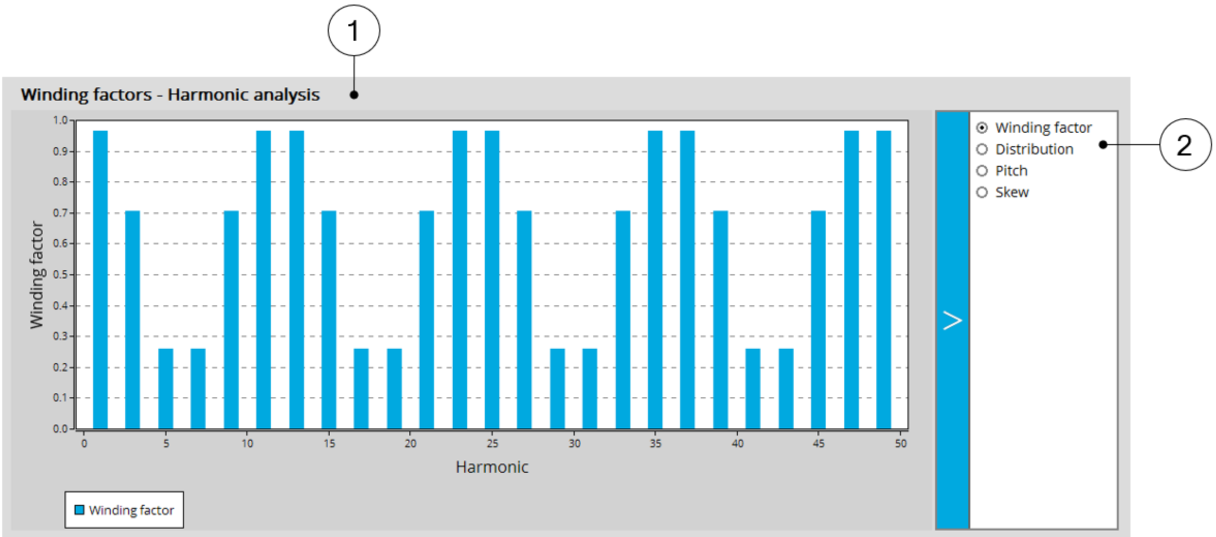
WINDING design area	
1	Select the spatial rerpesentation of the Magneto-Motive Force (M.M.F.)
2	Check the curves to display. Sum of phases M.M.F or M.M.F. provided by each phase. Note: Superimposition of harmonics is possible only if one or several harmonics have been selected. See explanation below.
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.

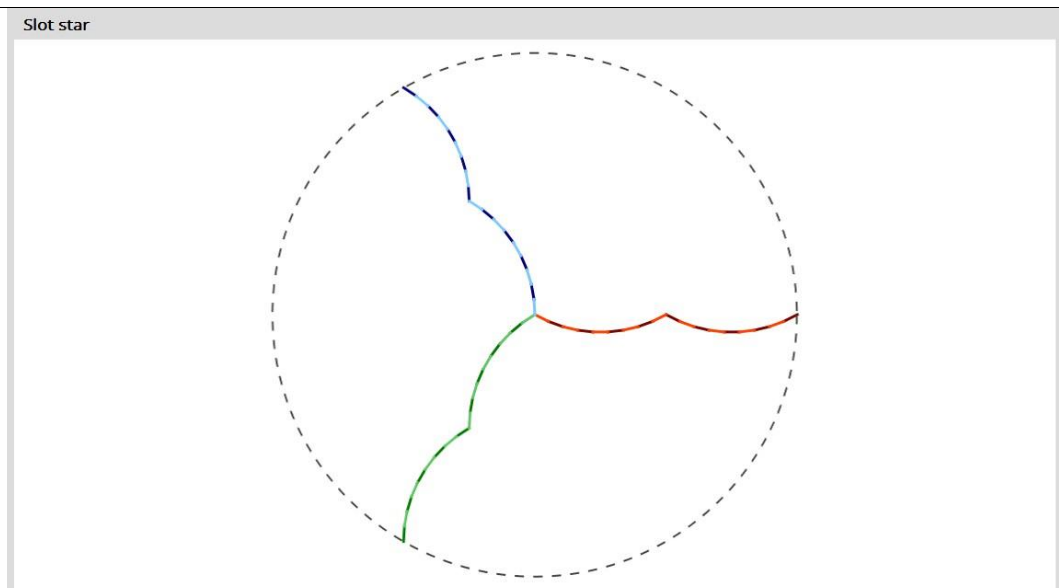
3.8 Quality criteria

3.8.1 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.

3.8.2 Slot star



Star slot	
1	The Slot star represents the total vector summation of voltages at the ends of each coil

4 HAIRPIN WINDING DESIGN

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.

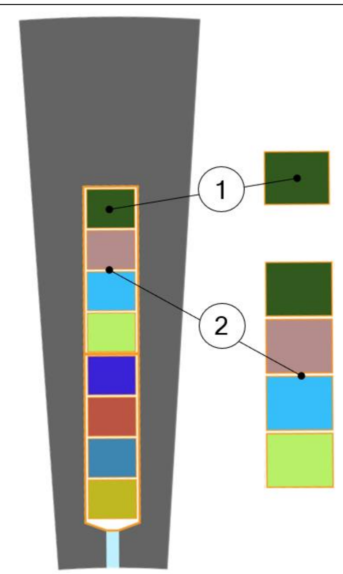
4.1 Differences with classical winding

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

- Only integer number of slots per pole and per phase are allowed (fractional number 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.

4.2 Terminology – Illustration



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).

4.3 Hairpin winding architecture - Inputs

4.3.1 Overview – Definitions

The following inputs define the winding architecture

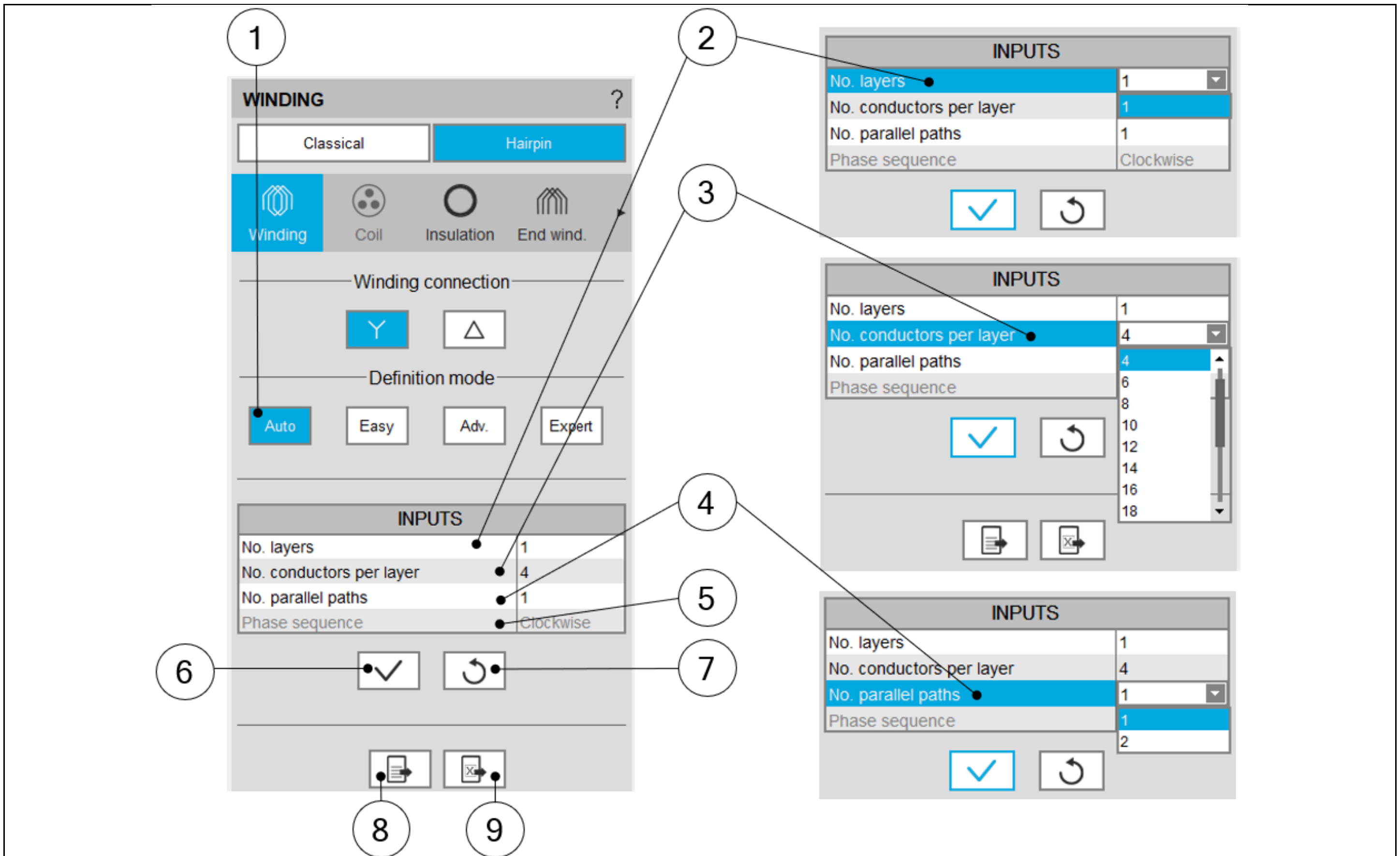
Label	Symbol	Tooltip, note, formula
Winding connection	Connect	Winding connection (Y – Wye or Δ - Delta)
Definition mode	*	Winding definition mode: Automatic, Easy, Advanced or Expert. See below section dedicated to the construction of the winding architecture
No. layers	N_{layers}	Number of layers – 1 or 2
No. conductors per layer	N_{cond}	Number of conductors per layer (only even number proposed)
No. parallel paths	P_{paths}	Number of parallel paths.
Phase sequence	*	Phase sequence (all modes).
Layer shift	*	The layer shift is defined by a number of slot pitches (Only available with 2 layers)

4.3.2 Automatic mode

4.3.2.1 User input parameters

Label	Symbol	Tooltip, note, formula
No. layers	N_{layers}	Number of layers – 1 only
No. conductors per layer	N_{cond}	Number of conductors per layer
No. parallel paths	P_{paths}	Number of parallel paths (1 or 2)
Phase sequence	*	Phase sequence

4.3.2.2 Building the winding architecture – Automatic mode – Main principles



Building the winding architecture - **Automatic** mode

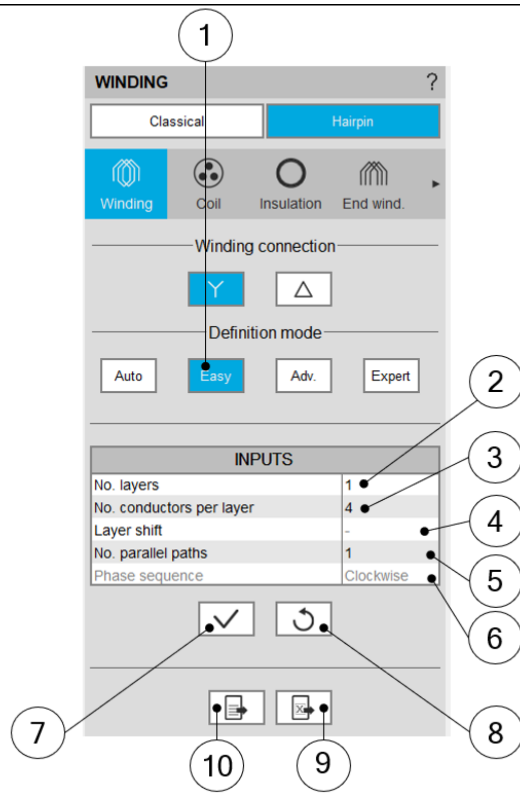
1	Selection of **Automatic** mode for building the winding architecture.
2	Number of layers - 1 is the only value available for this mode
3	Number of conductors per layer, must be even and limited to 30.
4	Number of parallel paths. The possible numbers of parallel paths are automatically computed and proposed to the user, 2 is the maximum proposed value according to the used hairpin pattern. When the user chooses a number of 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).
6	Button to apply inputs. Pressing the enter key twice applies inputs too.
7	Button to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
8	Icon to export winding data into *.txt or *.xlsx files.
9	Icon to export hairpin winding connection table into a *.xlsx file. This file can be shared and reloaded in another FluxMotor® session.

4.3.3 Easy mode

4.3.3.1 User input parameters

Label	Symbol	Tooltip, note, formula
No. Layers	*	Number of layers (1 or 2)
No. conductors per layer	*	No. conductors per layer
Layer shift	*	Layer shift in number of slot pitch (Only available with 2 layers)
No. parallel paths	P_{paths}	Number of parallel paths (1 or 2)
Phase sequence	*	Phase sequence

4.3.3.2 Building the winding architecture – Easy mode – Main principles



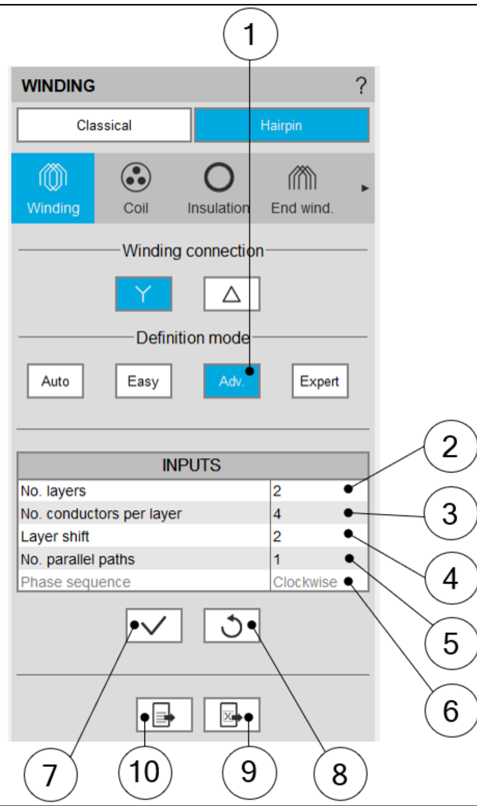
Building the winding architecture - **Easy** mode	
1	Selection of the **Easy** mode for building the winding architecture.
2	Selection of the number of layers. The number of layers are limited to 2.
3	Number of conductors per layer, it must be even and limited to 30.
4	The layer shift is defined by a number of slot pitch. It cannot exceed the number of slots per pole and per phase. (Only available with 2 layers).
5	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.
6	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).
7	Button to apply inputs. Pressing the enter key twice applies inputs too.
8	Button to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
9	Icon to export winding data into *.txt or *.xlsx files.
10	Icon to export hairpin winding connection table into a *.xlsx file. This file can be shared and reloaded in another FluxMotor® session.

4.3.4 Advanced mode

4.3.4.1 User input parameters

Label	Symbol	Tooltip, note, formula
No. Layers	*	Number of layers (1 or 2)
No. conductors per layer	*	Number of conductors per layer
Layer shift	*	Layer shift in number of slot pitch (Only available with 2 layers)
No. parallel paths	P_{paths}	Number of parallel paths (1 or 2)
Phase sequence	*	Phase sequence

4.3.4.2 Building the winding architecture – Advanced mode – Main principles



Building the winding architecture - **Advanced** mode

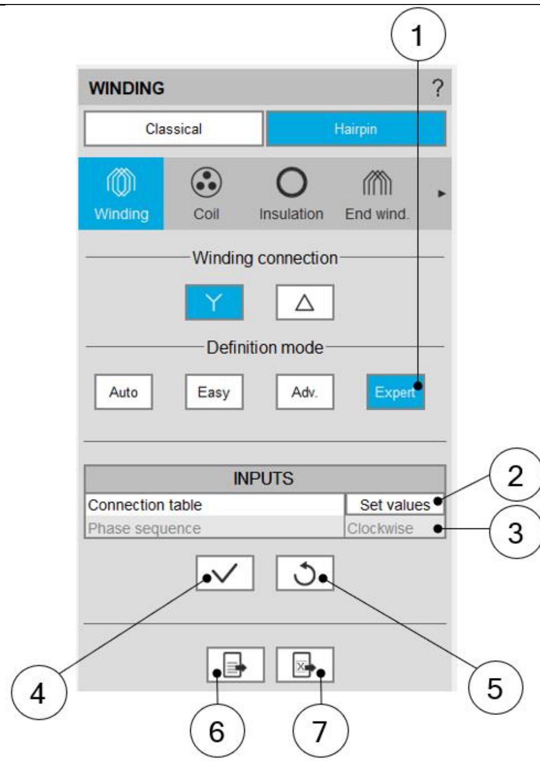
1	Selection of the **Advanced** mode for building the winding architecture.
2	Selection of the number of layers. The number of layers are limited to 2.
3	Number of conductors per layer, it must be even and limited to 30.
4	The layer shift is defined by the number of slot pitch. It cannot exceed the number of slots per pole and per phase. (Only available with 2 layers).
5	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 hairpin pattern used. When the user chooses several parallel paths. The connections on the winding scheme are automatically updated.
6	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).
7	Button to apply inputs. Pressing the enter key twice applies inputs too.
8	Button to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
9	Icon to export winding data into *.txt or *.xlsx files.
10	Icon to export hairpin winding connection table into a *.xlsx file. This file can be shared and reloaded in another FluxMotor® session.

4.3.5 Expert mode

4.3.5.1 User input parameters

Label	Symbol	Tooltip, note, formula
No. Layers	N_{Layers}	Number of layers (1 or 2)
No. conductors per layer	*	Number of conductors per layer (even)
No. slots/pole/phase to fill	*	Number of slots per pole and per phase to fill
Phase sequence	*	Phase sequence (all modes)

4.3.5.2 Main principles



Building the winding architecture - **Expert** mode

1	Selection of the **Expert** mode for building the winding architecture.
2	“Set values” means opening the dialog box to fill the connection table. See illustration below.
3	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).
4	Button to apply inputs. Pressing the enter key twice applies inputs too.
5	Button to restore default input values. Default values are those which define the winding architecture by using the automatic mode.
6	Icon to export winding data into *.txt or *.xlsx files.
7	Icon to export hairpin winding connection table into a *.xlsx file. This file can be shared and reloaded in another FluxMotor® session.

4.3.5.3 Build a coil with expert mode

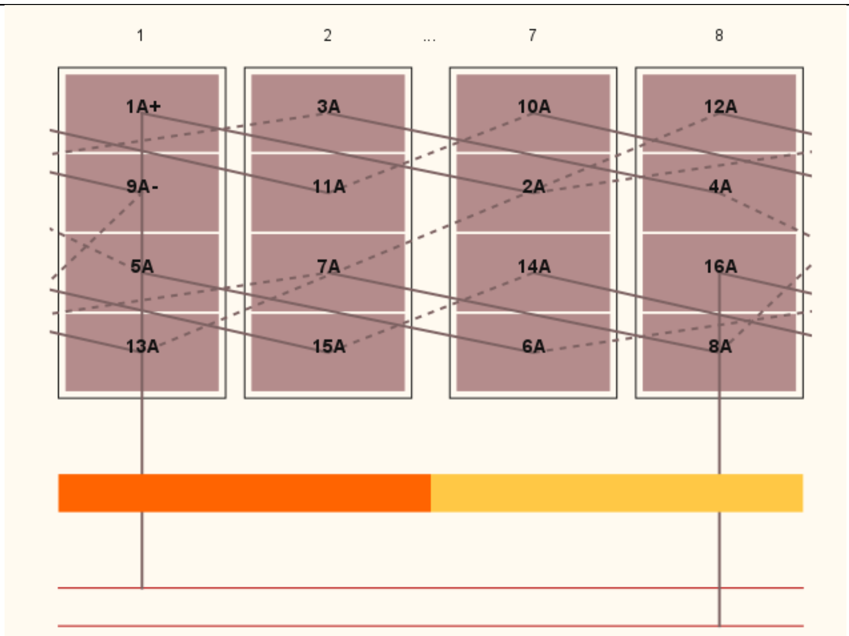
Building the winding architecture – Filling of the connection table

1	Dialog box to define a connection table with expert mode.
2	Box 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	Selection of the number of layers. Number of layers are limited to 2
5	Number of conductors per layer (This value must be even)
6	Number of slots per pole and per phase to set. No more than 2 times the number of slots per pole and per phase
7	Dynamic view of the hairpin winding updated in real time in function of the filling status of the connection table.
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
9	Icon to apply inputs and close the panel.
10	Icon to remove everything in the connection table (*Erase connection table data*).
11	Icon to cancel action and close the panel.

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.

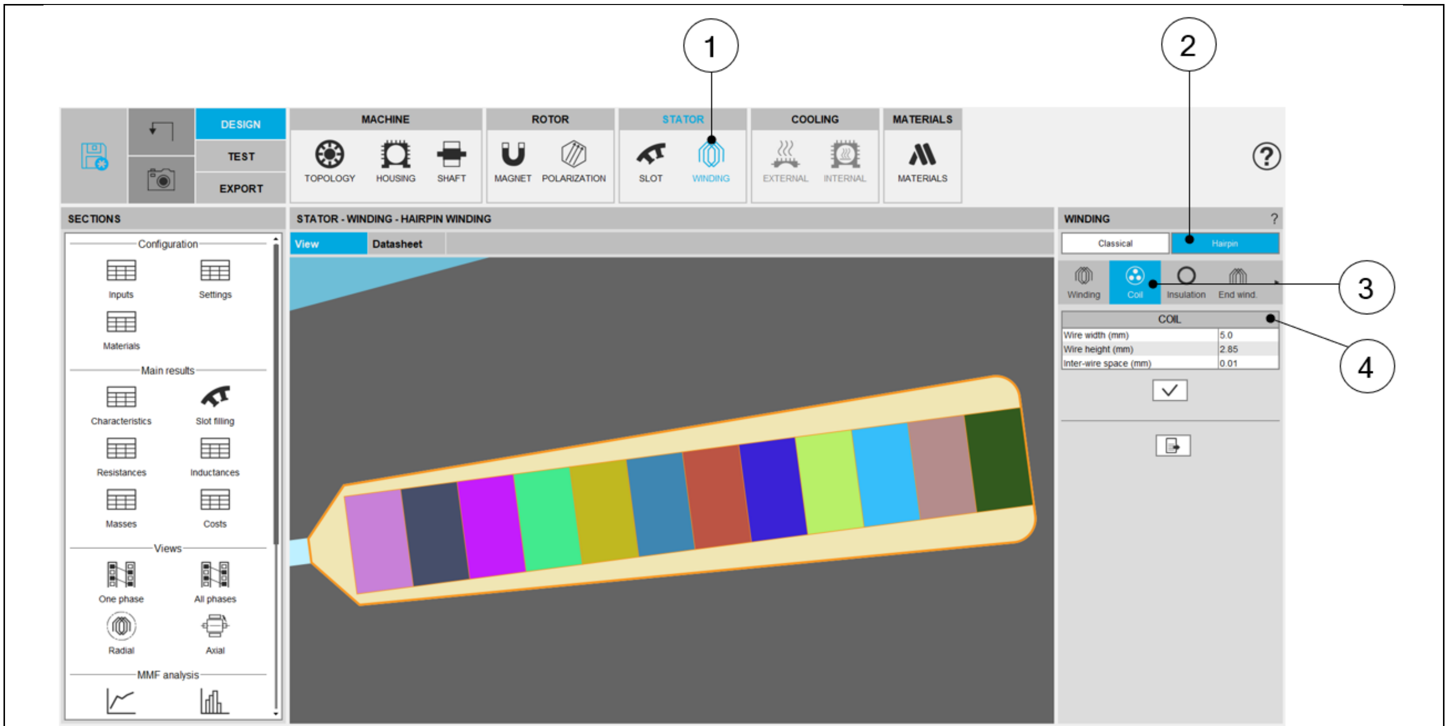
Example:
How to define a parallel path composed of 16 conductors in which the first 8 rotates in the clockwise way (conductor 1 -> 8) and the other 8 rotates in the counterclockwise way (conductor 9-> 16)?
The first conductor of the first 8 conductors must be defined as “1A+” to rotate in the clockwise 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?

4.4 Hairpin coil design - Inputs

4.4.1 Overview - Definitions



Definition of the hairpin coil	
1	Selection of the STATOR subset: WINDING panel (Click on the icon WINDING).
2	Selection of hairpin winding technology.
3	Coil settings allow describing the coil composition (wires dimensions mainly)
4	Description of the coil dimensions (Width, height, inter wire space).

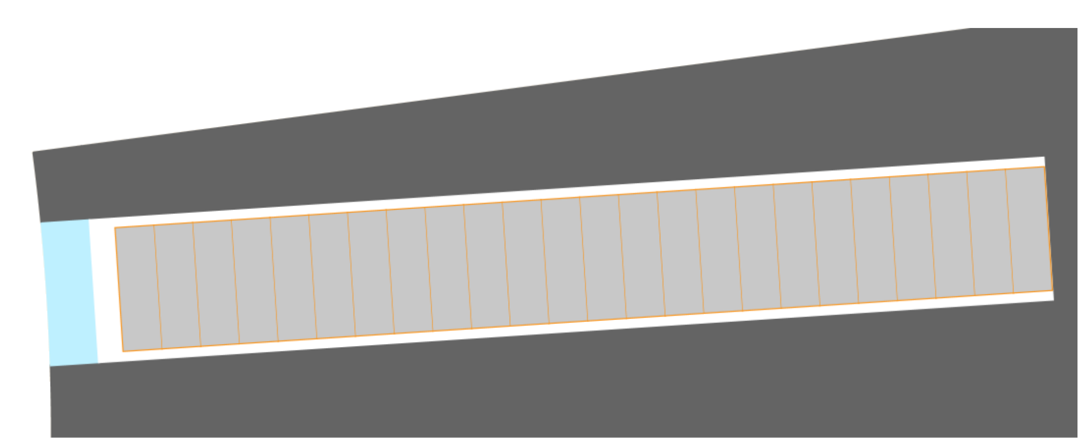
The following inputs define the coil and how is filled the slots

Label	Symbol	Tooltip, note, formula
Wire width	W_{wire}	Wire width (without insulation), for rectangular shape wire
Wire height	H_{wire}	Wire height (without insulation), for rectangular shape wire
Inter-wire space	w/w	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.

4.4.2 Relevance of the slot filling

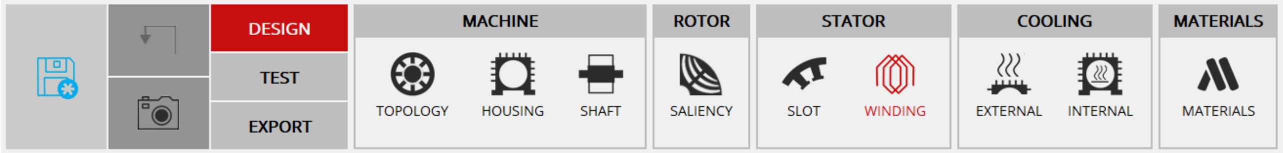
When the number of wires (induced by the number of conductors per layer and the number of layers) are higher than allowed by the slot free area, the wires are grayed in the slot filling view. This is to inform the user that the number of wires must be decreased, so, with hairpin technology, the number of conductors per layer.

In that case, the design of the winding is not possible; the machine cannot be built or tested.



Grayed rectangular shape type wire

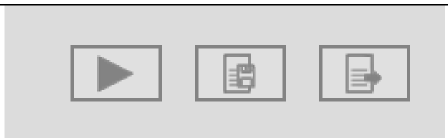
Motor Factory Design environment button and winding icon in the Stator section are colored in red. This means that there exist a fault in the design, which must be corrected.



Motor Factory Design environment button 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.



The tests cannot be performed

4.5 Hairpin winding insulation design - Inputs

4.5.1 Overview - Definitions

Here are all the available insulation types.

Label	Symbol	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).

4.5.2 Illustrations for rectangular shape type wire

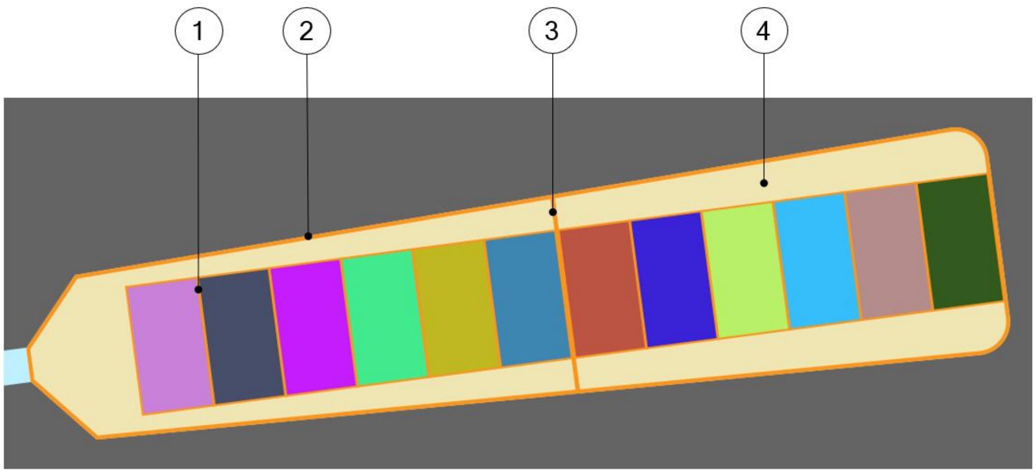


Illustration of winding insulation for rectangular shape type wire

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

4.6 End winding design of hairpin winding – Inputs

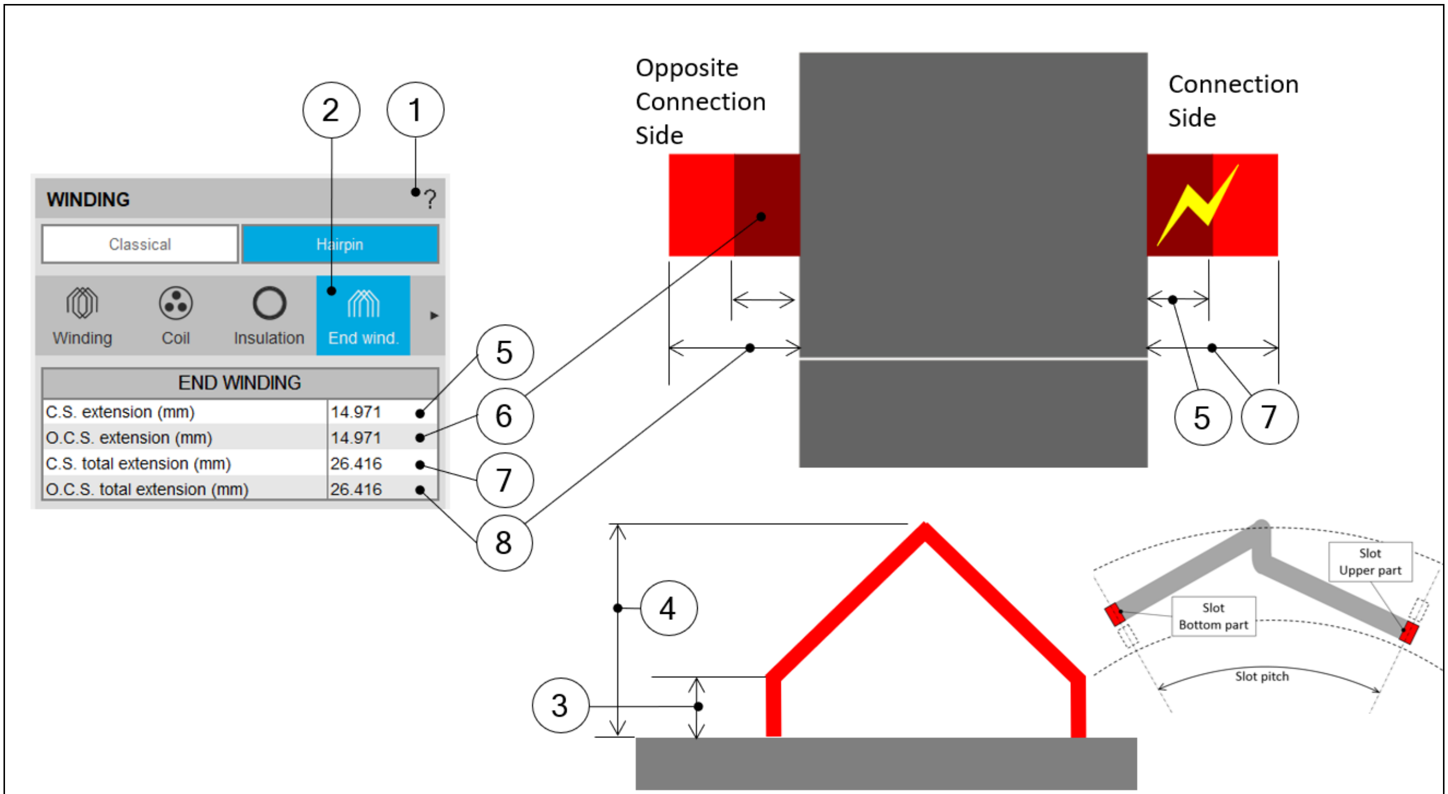
4.6.1 Overview - definitions

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.

4.6.2 End-winding topology – Y-Shape

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



Building the winding – End-winding topology and dimensions	
1	Selection of the Hairpin environment
2	Selection of the **END-WINDING** tab.
3	Straight extension of the Y-Shape end-winding topology = User input parameter.
4	Total extension of the Y-Shape end-winding topology = User input parameter.
5	Definition of the connection side straight extension (ref. 3).
6	Definition of the opposite connection straight extension (ref. 3).
7	Definition of the connection side total extension (ref. 4).
8	Definition of the opposite connection side total extension (ref. 4).

4.7 Calibration factors definition - Inputs

4.7.1 Overview - Definitions

Label	Symbol	Tooltip, note, formula
Ref. temperature	*	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).
Winding resistance factor	*	Setting of the “Resistance factor”. It allows adjusting computation result of resistance with resistance measurement. Thus, the resulting phase resistance value is considered.
End winding inductance factor	*	Setting of the “Inductance factor”. It allows modifying the computation result of end-winding inductance. Thus, the resulting end-winding inductance value is considered.
Ref. max. Line-Line voltage	Umax	Reference maximum Line-Line voltage. It allows evaluating the voltage drop between the conductors.
Voltage drop limit	*	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).

4.8 Potting design – Inputs

4.8.1 Overview - Definitions

“Potting” section is available only when the housing is defined with a frame (circular or square shape).
Please refer to section **2.7 (Potting design – Inputs)** since it has the same definition as classical winding topology.

5 HAIRPIN WINDING OUTPUTS

5.1 Characteristics

5.1.1 Winding

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.
No. conductors per layer		Number of conductors per layer
Layer shift		Layer shift in number of slot pitch (Only available with 2 layers)
Coil layout	*	Coil layout inside the slot – Full or Superimposed
Winding connection	Connect	Winding connection (Y – Wye or Δ - Delta)
Winding type	*	The winding type: Wave
Current balance of parallel path		Current balance of parallel path – Yes or No
No. slots / pole / phase	q	Number of slots per pole and per phase. $q = \frac{Nslots}{2p \times m}$ (p is the number of pole pairs and m the number of phases)
Pole pitch	τ_{pole-z}	$\tau_{pole-z} = \frac{No.slots}{2p}$ (Nslots = number of slots and p= 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.
Coil pitch	τ_{coil}	The number of slot pitch between coil input and coil output is equal to the pole pitch for Auto, Easy and Advanced mode. For Expert mode, it is not computed because the coil pitch can be equal to different values.

5.1.2 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.

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.

5.1.3 Coil

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

5.1.4 Lengths

Please refer to section **3.1.4** for more information about “**Lengths”** since it’s the same as Classical winding topology.

5.1.5 Areas in slot

Please refer to section **3.1.5** for more information about “**Areas in slot”** since it’s the same as Classical winding topology.

5.1.6 Fill factors

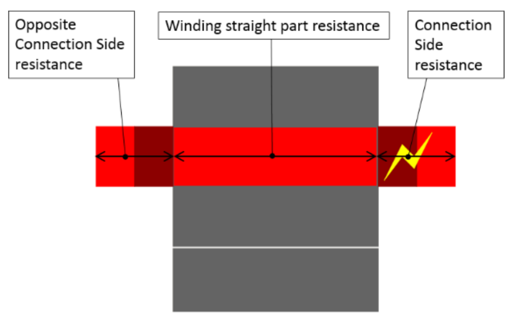
Please refer to section **3.1.6** for more information about “**Fill factors”** since it’s the same as Classical winding topology.

5.2 Slot filling

The slot filling result gives the user a realistic view of the filling of the slot in function of the setting options.
For additional information, please refer to 4.4 Hairpin coil design - Inputs.

5.3 Resistances

5.3.1 Resistances – Resistance at 20°C and at ref. temperature

Label	**Symbol**	**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)

5.4 Inductances

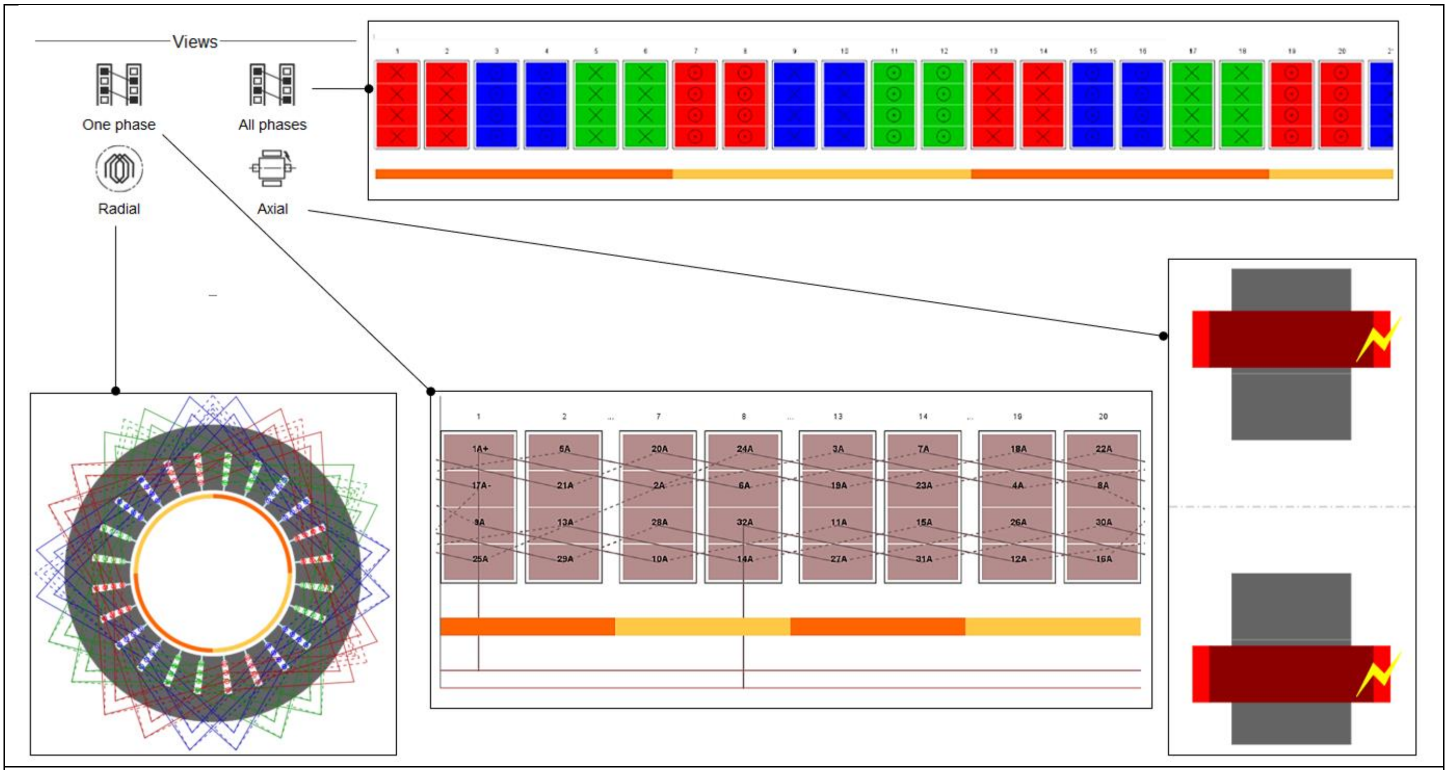
Label	**Symbol**	**Tooltip, note, formula**
Phase		Phase inductance
Parallel path number		Number of parallel paths
End winding	*	Total end winding inductance (including the two sides of the machine).
C.S. end winding	*	Connection side end winding inductance.
O.C.S. end winding	*	Opposite connection side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

5.5 Masses and costs

For additional information, refer to section 3.5 dedicated to masses and costs since it's the same as Classical winding topology.

5.6 Visualization of the winding architecture



Visualization of the winding architecture

5.7 Magneto-Motive Force analysis

For additional information, refer to section 3.7 dedicated to MMF analysis since it's the same as Classical winding topology.

5.8 Quality criteria

5.8.1 Winding factors

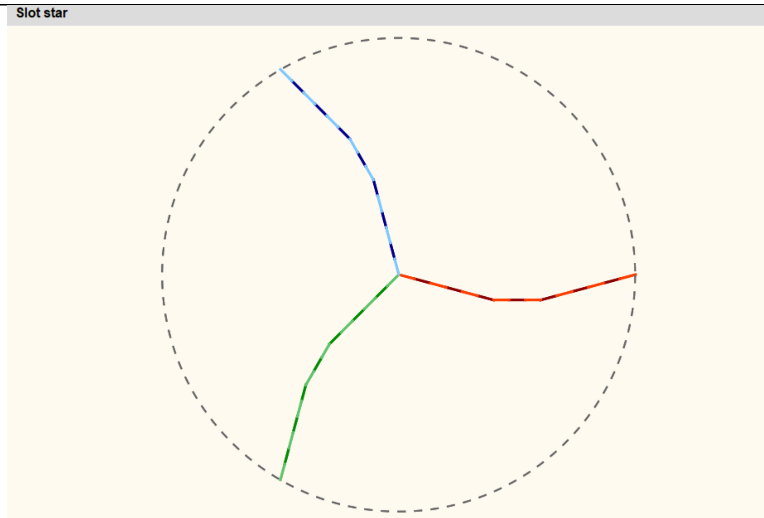
For additional information, refer to section **3.8** dedicated to the **winding factor** since it's the same as Classical winding topology.

For unbalanced hairpin configurations, as the results are not relevant, therefore, they are not computed and displayed.

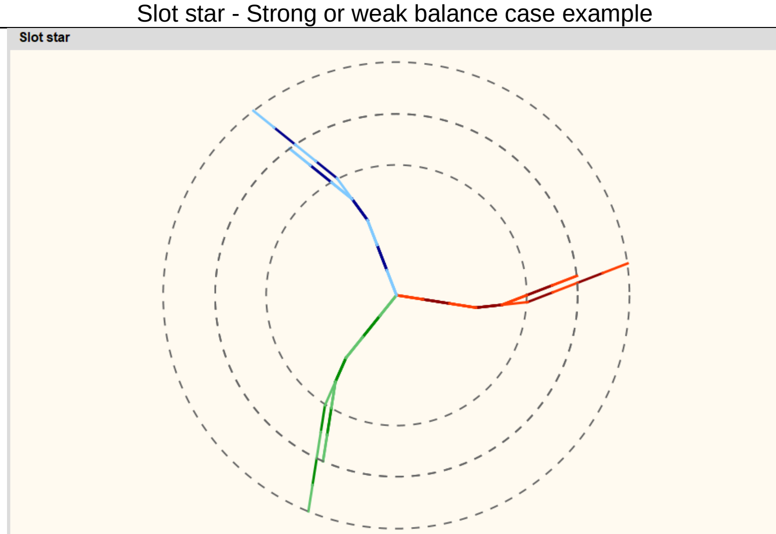
Note, the unbalanced hairpin configurations are characterized by at least one parallel path which is different in term of voltage and impedance from the other parallel paths.

5.8.2 Slot star

The Slot star represents the total vectorial sum of voltages, at the ends of each coil, for each parallel path.
A slot star is computed and displayed for each parallel path.



Slot star - Strong or weak balance case example



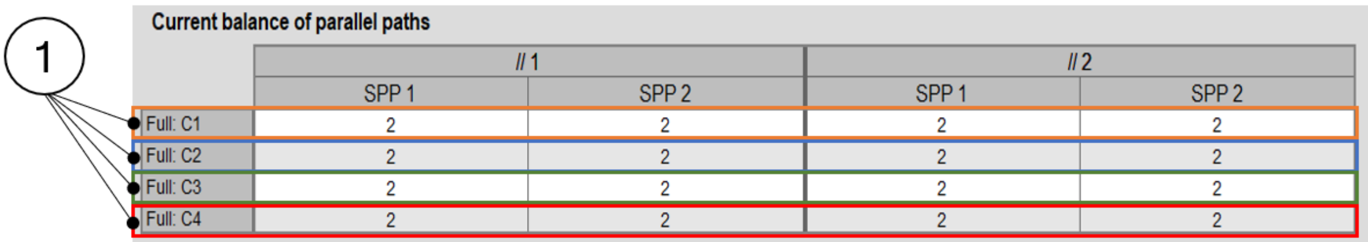
Slot star - Unbalance case example

1	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

5.8.3 Parallel paths

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

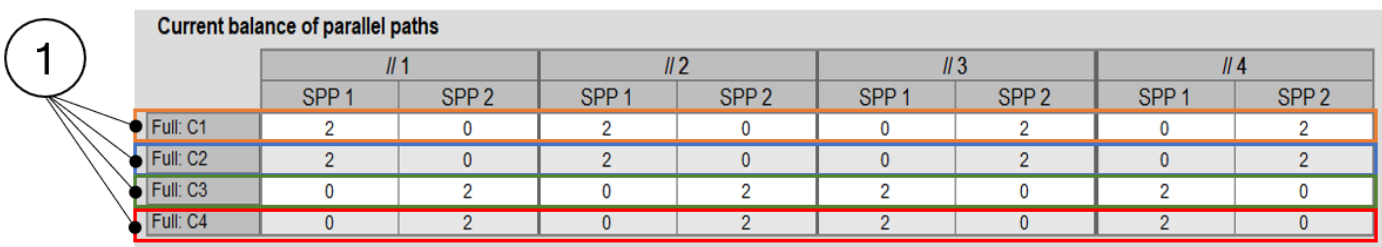


Current balance of parallel paths

	// 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

1

Current balance of parallel paths

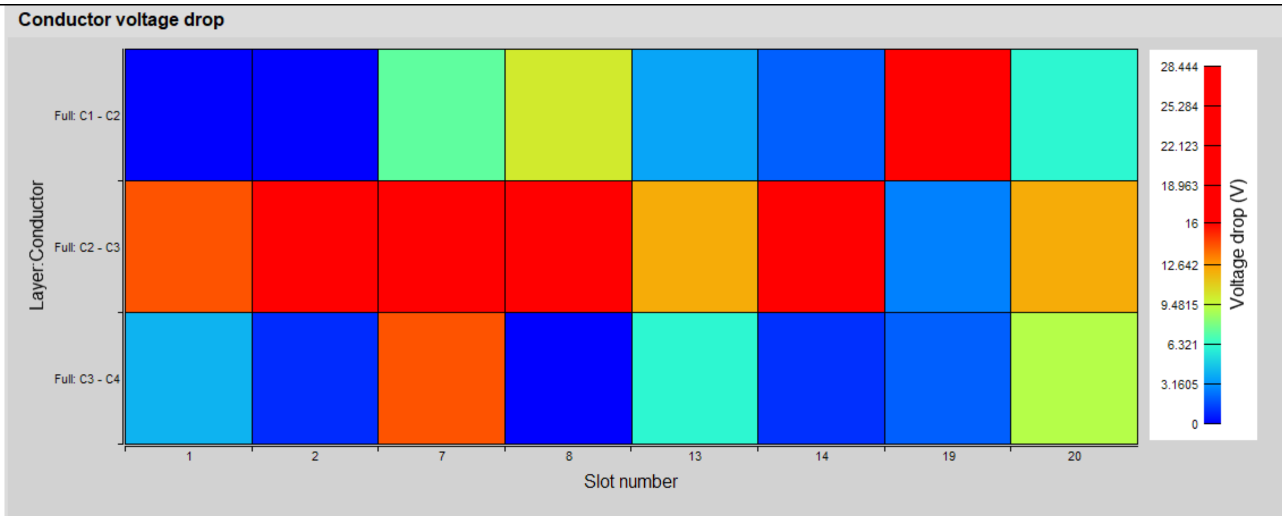
	// 1		// 2		// 3		// 4	
	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2	SPP 1	SPP 2
Full: C1	2	0	2	0	0	2	0	2
Full: C2	2	0	2	0	0	2	0	2
Full: C3	0	1	0	2	2	1	2	0
Full: C4	0	1	0	2	2	1	2	0

	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.

5.8.4 Voltage drop



Conductor voltage drop	
1	Inside each slot, the voltage drop 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 in visualizing quickly where are the hot point from an electrical potential difference point of view.

6 CHOICE OF WINDING MATERIALS

All the materials needed for building the winding (conductors and insulations) are distributed in the section "Materials" of the Motor Factory - Stator - Design environment.
All the materials are selected from the material database.