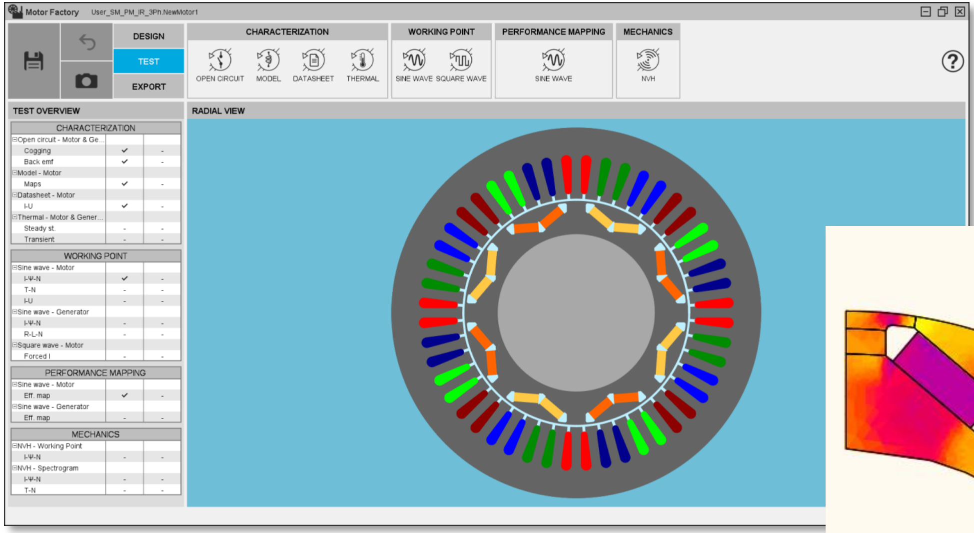

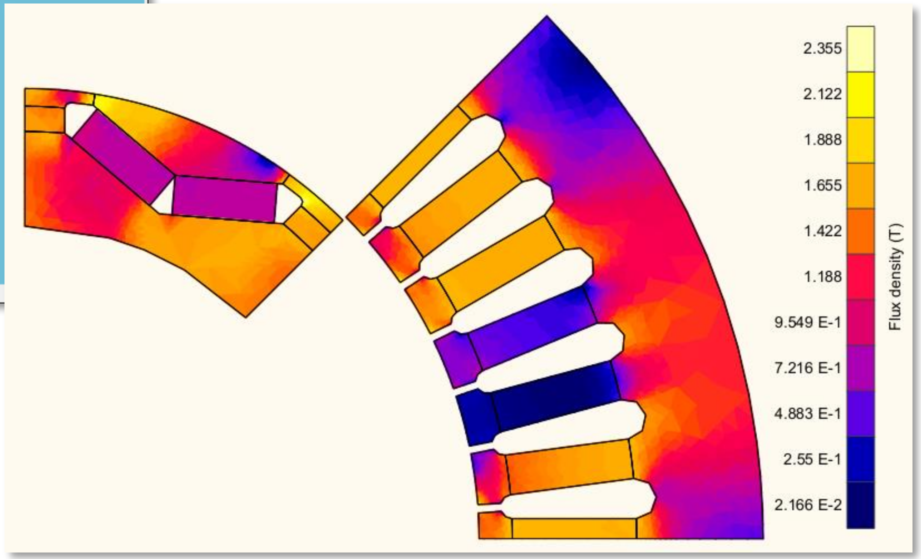

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FLUXMOTOR OVERVIEW TUTORIAL

March 2023

Introduction

In this tutorial, users will learn the basic workflow and the functionalities available in FluxMotor to:

- *Create a geometry in the Design area of Motor Factory*
- *Validate your topology by running tests and analysis in the Test area of Motor Factory*
- *Export your FluxMotor project to Flux*

The following training materials will be provided to you:

- *This step-by-step presentation*

At the end of the tutorial, you are expected to:

- *Re-create a given IPM motor topology and run all the tests available in FluxMotor on it.*

Related support documents:

- *Online user notes and technical documents of FluxMotor*

Outlook

INTRODUCTION TO FLUXMOTOR

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Introduction - General Overview of FluxMotor

- **FluxMotor** is a multiphysics software dedicated to the design of rotating electrical machines, such as electric motors, with the simplest and the most intuitive user interface in the market.
- It allows engineers to accelerate the design of machines and to quickly evaluate several machine configurations by considering the electromagnetic, thermal and vibroacoustic aspects. A few minutes are enough to select the most promising solution.
- The intuitive environment of FluxMotor allows users - from generalist to expert - to efficiently design, analyze and optimize their electric motors.
- If required, the exports of FluxMotor projects to other Altair solutions allow carrying out advanced studies to be carried out.

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Introduction - General Overview of FluxMotor

Basic hypothesis

Finite element calculations are carried out in 2D with Flux 2D

The finite element calculations are used in order to consider the saturation and the non-linearities of the materials with good precision.

FE calculations are invisible to the user, to maintain the ease of use.

Iron losses are neglected at the rotor

Since the most important part of the losses is in the stator, the iron losses in the rotor are neglected for the calculation of the efficiency.

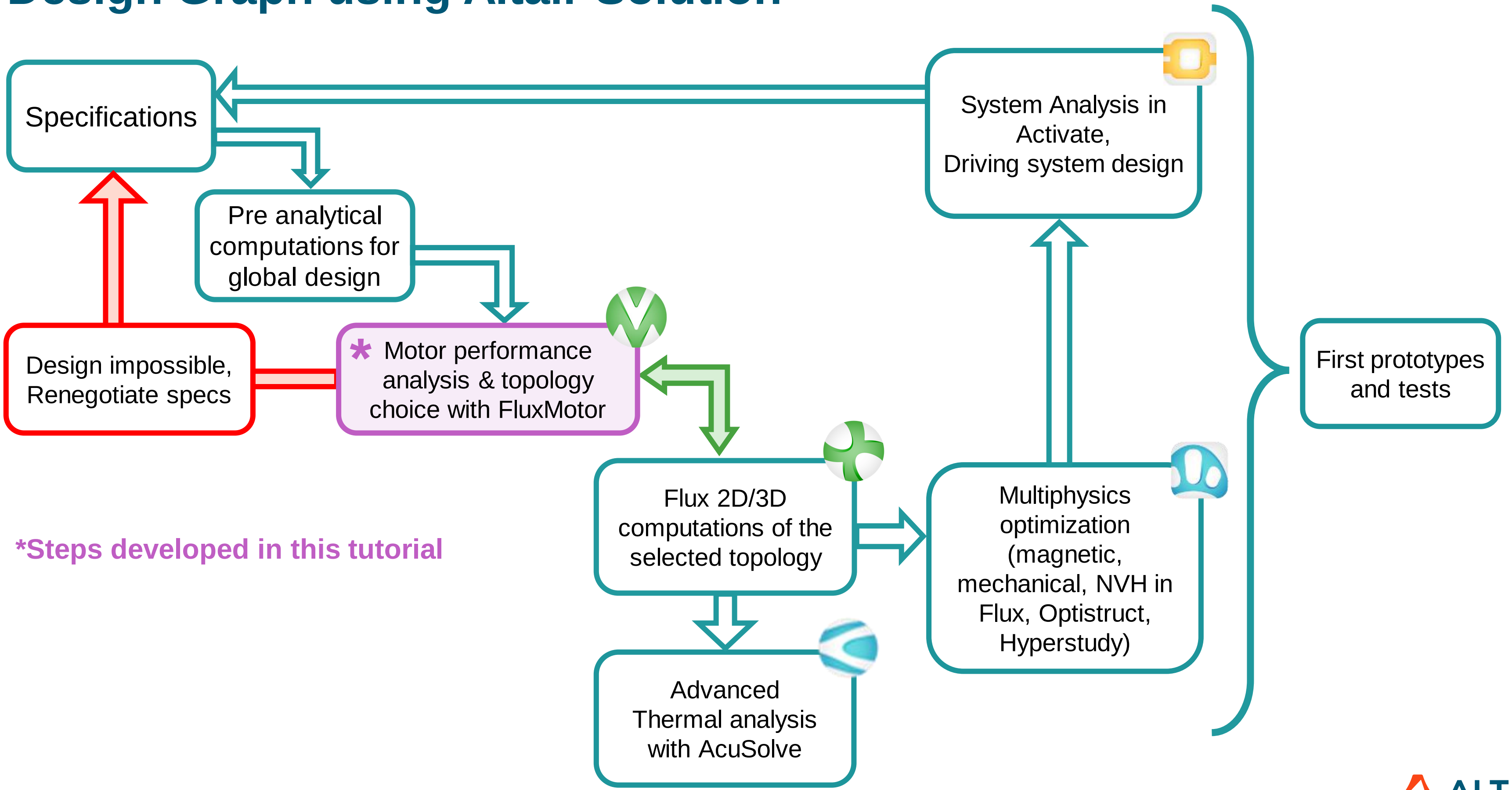
However, it is still possible to calculate it by exporting the FluxMotor project to solve in Flux 2D.

Joule losses are neglected in magnets

The most important part of the Joule losses is found in the stator windings, the ones in the magnets are therefore neglected for the calculation of the efficiency.

It is also possible to calculate it in Flux 2D.

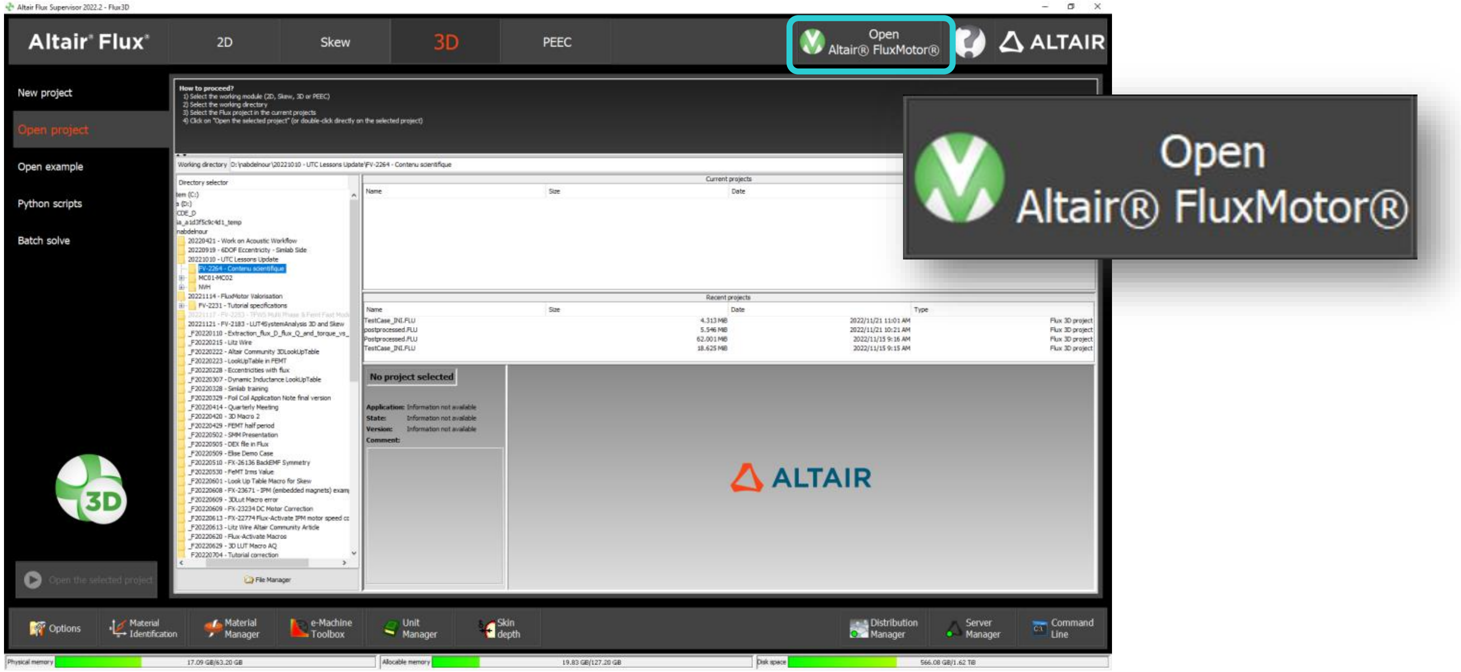
Design Graph using Altair Solution



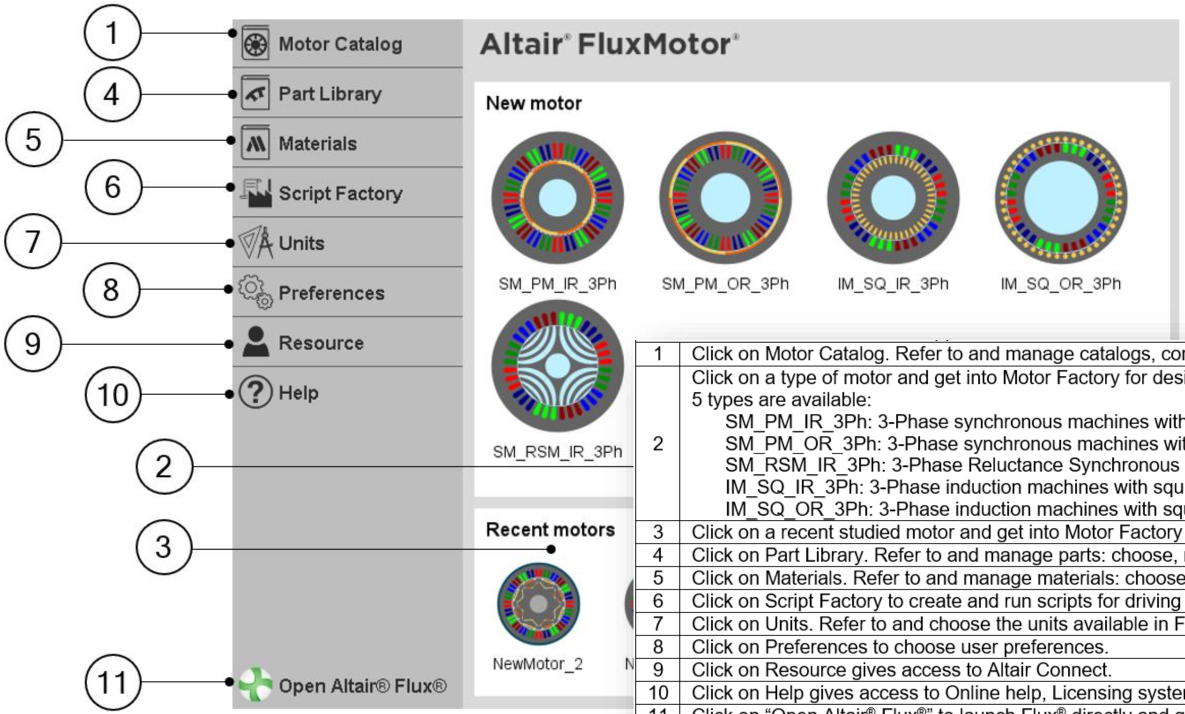
*Steps developed in this tutorial

Open FluxMotor

- Directly using your FluxMotor desktop shortcut, or
- Indirectly via the Flux Supervisor



FluxMotor Supervisor – General overview



1	Click on Motor Catalog. Refer to and manage catalogs, compare, and choose motors.
2	Click on a type of motor and get into Motor Factory for designing and testing motors. 5 types are available: SM_PM_IR_3Ph: 3-Phase synchronous machines with permanent magnets – Inner rotor SM_PM_OR_3Ph: 3-Phase synchronous machines with permanent magnets – outer rotor SM_RSM_IR_3Ph: 3-Phase Reluctance Synchronous Machines – Inner rotor IM_SQ_IR_3Ph: 3-Phase induction machines with squirrel cage – Inner rotor IM_SQ_OR_3Ph: 3-Phase induction machines with squirrel cage – outer rotor
3	Click on a recent studied motor and get into Motor Factory for designing and testing motors
4	Click on Part Library. Refer to and manage parts: choose, modify, or create
5	Click on Materials. Refer to and manage materials: choose, modify, or create.
6	Click on Script Factory to create and run scripts for driving FluxMotor® applications.
7	Click on Units. Refer to and choose the units available in FluxMotor®.
8	Click on Preferences to choose user preferences.
9	Click on Resource gives access to Altair Connect.
10	Click on Help gives access to Online help, Licensing system and information about FluxMotor® and Altair® HyperWorks®
11	Click on “Open Altair® Flux®” to launch Flux® directly and quickly from FluxMotor® supervisor

FluxMotor - Principle Applications

- **Motor Catalog:** Project management tool to refer and manage catalogs, compare and choose motors. Standard or user-created motors are available.
- **Motor Factory:** The main application for designing machines, evaluating their performance, and if necessary, accessing other Altair solutions to carry out advanced studies. A starting topology is proposed for each type of machine (New motor) or access to recently studied motors (Recent motors).
- **Part Library:** Management of machine components such as slots, magnets, etc... choice, modification or creation.
- **Part Factory**: Accessible from Part Library, it is a dedicated space for viewing, modifying or creating parametrized parts.
- **Materials:** A comprehensive and evolutive material database. View and manage materials: Choice, modification or creation.
- **Script Factory:** Allows you to drive FluxMotor via Python files and launch an automated experimental design.
- **Units:** Refer and choose the units available in the software.
- **User preferences:** Choice of user preferences.

DEFINITION OF THE GEOMETRY AND PHYSICS OF AN ELECTRIC MOTOR MODEL

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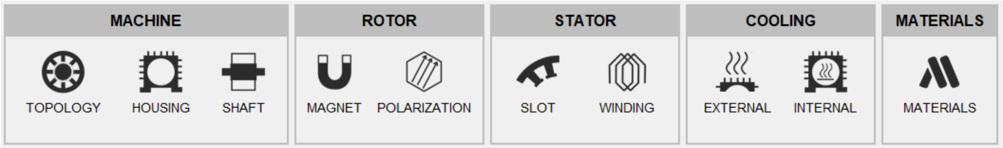
Motor Factory – Geometric and Physical Definition of the Motor



- **Topology:** Definition of structural data of the machine - Dimensions - Number of poles / slots, etc.
- **Housing:** Definition of the motor casing – Necessary to perform thermal and vibro-acoustic calculations
- **Shaft:** Definition of the rotor shaft and bearings – Necessary to perform thermal calculations
- **Magnet:** Definition of magnets - Choice of topology and dimensions and skewing of the rotor
- **Polarization:** Definition of the magnetization orientation of the magnets
- **Slot:** Definition of slots - Choice of topology, dimensions, skewing and shape of the stator laminations
- **Winding:** Definition of the winding – Architecture, coils, conductors, electrical insulation, filling of slots, etc.
- **External cooling:** Definition of the characteristics of the external cooling of the machine - Convection, radiation, cooling system. Possible, only if the casing has been defined
- **Internal cooling:** Definition of the characteristics of the internal cooling of the motor - Convection, radiation, parasitic airgap, slots, etc. Possible only if the casing, the shaft and the bearings have been defined
- **Materials:** Choice of machine materials from the materials database

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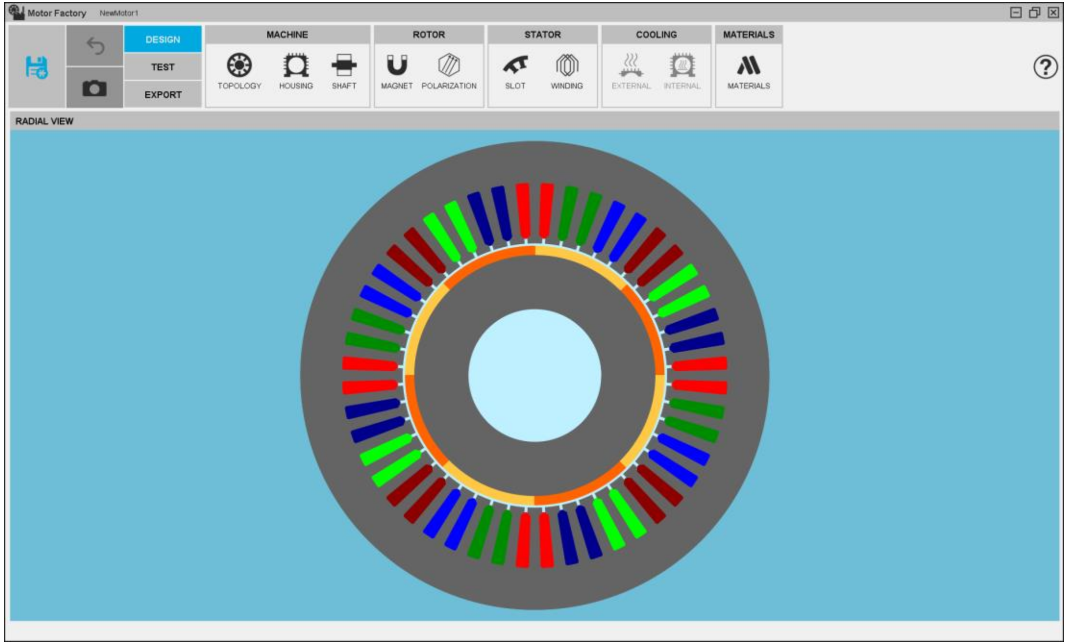
Motor Factory – Motor Modification

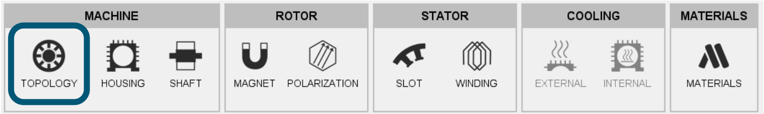
Double clicking on one of the motor types in "*New motor*" loads the corresponding default motor in the Motor Factory. From there, one can modify the topology of the components (slots or magnets) along with the dimensions, and thereafter carry out the analysis of the defined motor.

- In this tutorial, choose "***SM_PM_IR_3Ph***".



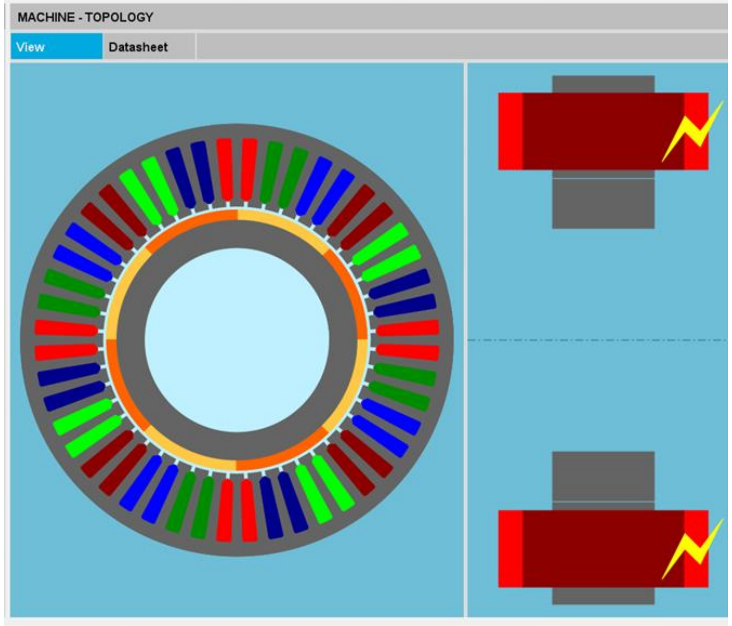
Stuctural Data

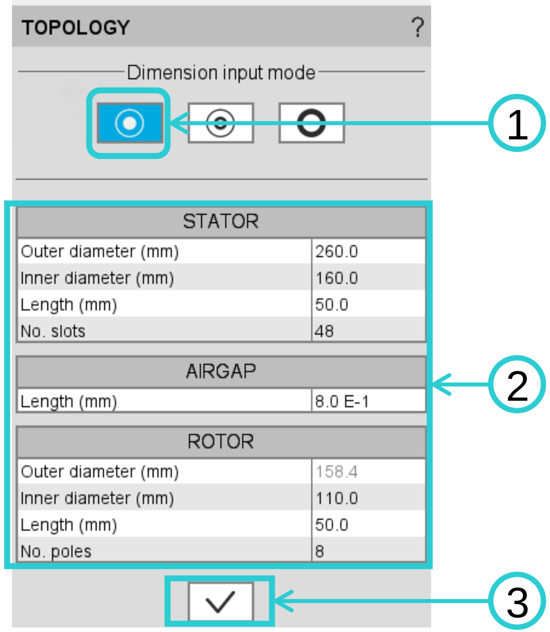
Dimensions and topology



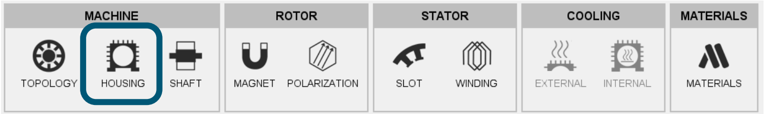
- The structural dimensions are important data in the specifications that are directly linked to the space constraints.
- The topology will affect the cost of the motor, since it can add the manufacturing difficulties and the material costs.

Step	Action
1	Choose to work with fixed outer diameter
2	Fill in motor parameters
3	Validate

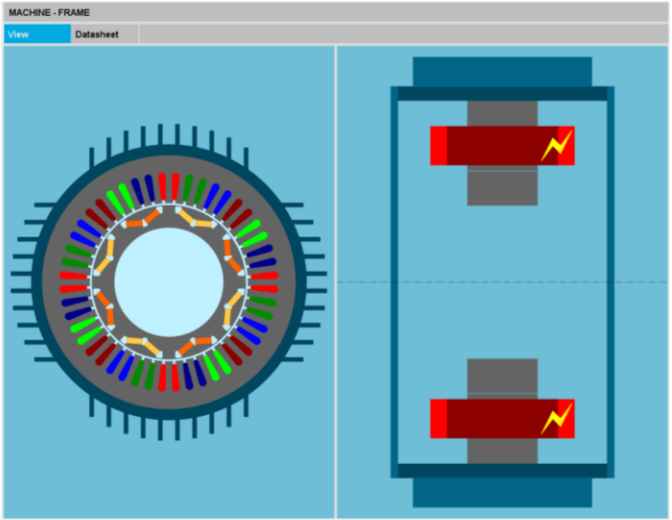


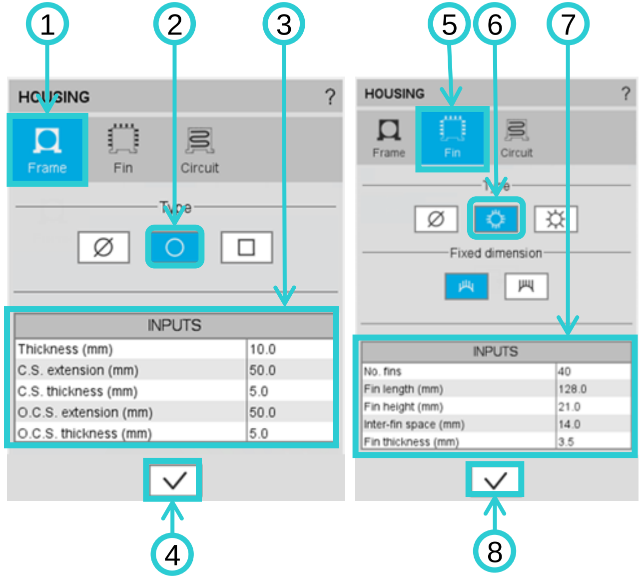


Housing Definition



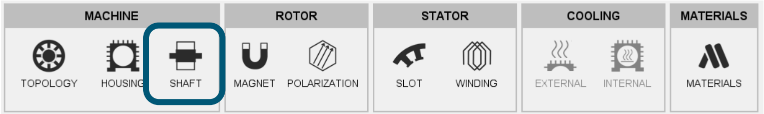
- The housing definition makes it possible to evaluate the feasibility of a project in terms of size and mass (cost).
- By defining the housing, many tests such as thermal or NVH analysis will be unlocked.



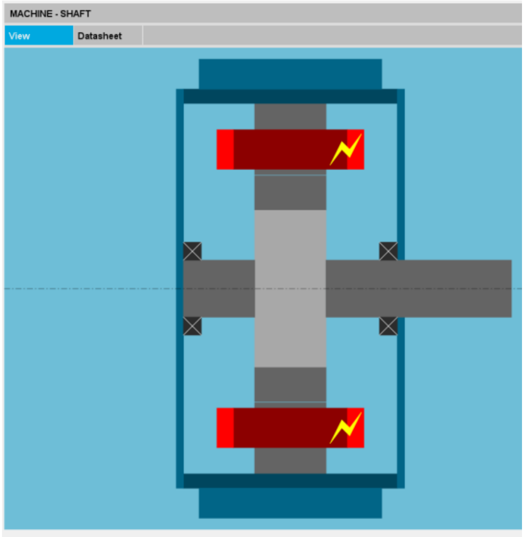


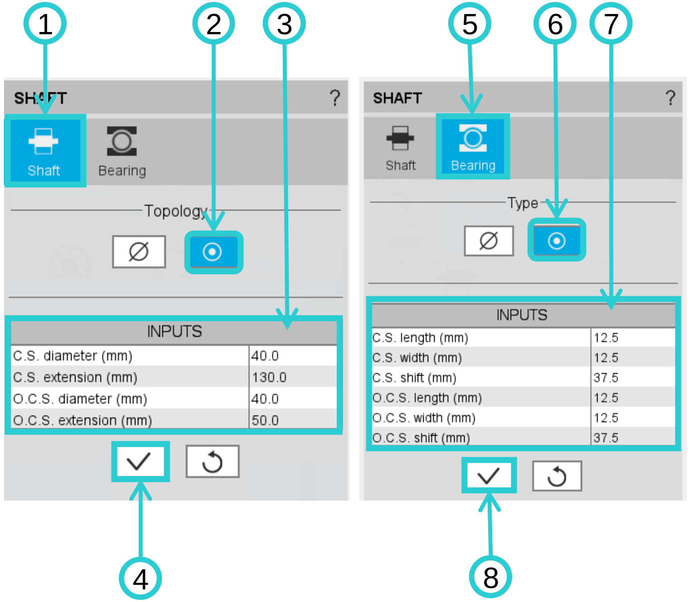
Step	Action
1	Enter frame definition context
2	Add a circular frame
3	Fill in frame dimensions
4	Validate frame options
5	Enter fin definition context
6	Add parallel fins
7	Fill in fins dimensions
8	Validate fin options

Rotor Shaft Definition



- The definition of rotor shaft makes it possible to assess the feasibility of a project in terms of size and mass (cost).
- The central part is magnetically represented and affects the electromagnetic behavior of the motor.
- Defining the rotor shaft (with its bearings) will unlock the thermal tests.





Step	Action
1	Enter shaft definition context
2	Add a shaft
3	Fill in shaft dimensions
4	Validate shaft options
5	Enter bearings definition context
6	Add bearings
7	Fill in bearing dimensions
8	Validate bearing options

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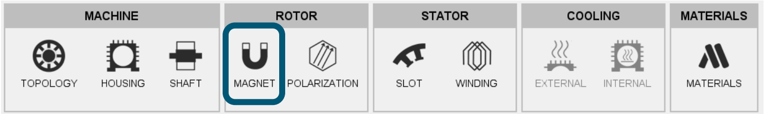
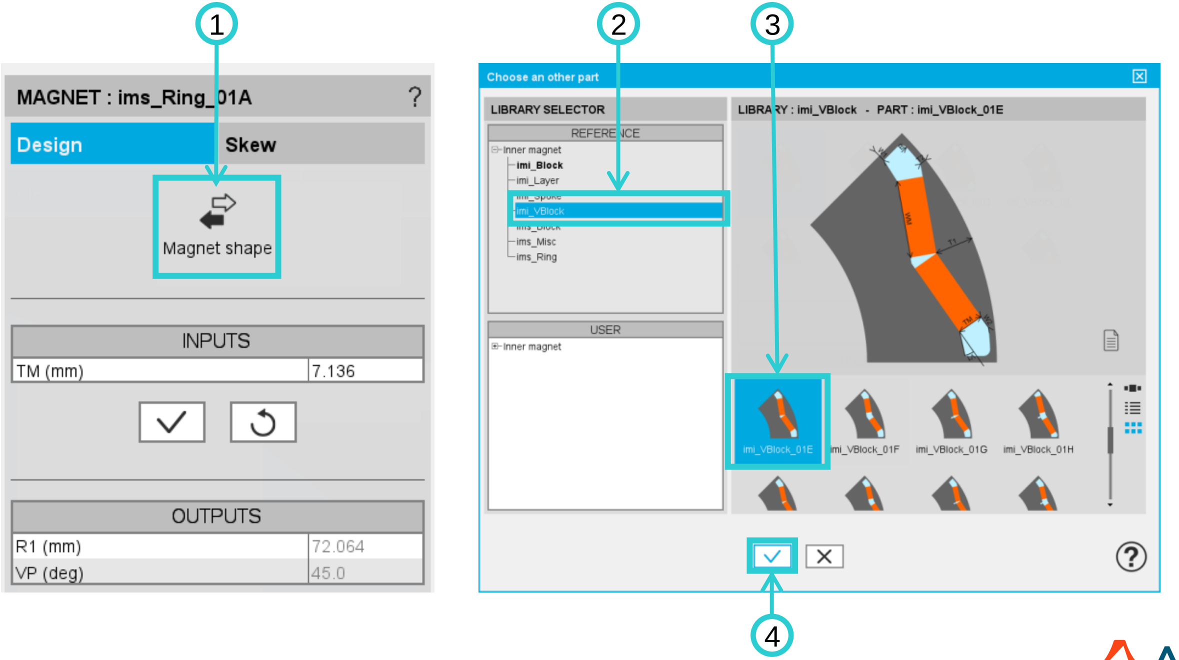
Magnet Topology Definition



- The topology and dimensions of the magnets affect the motor performance, torque, torque ripple, motor efficiency, and more precisely, the motor power and cost.
- Accurate definition of the magnets is essential to optimize the performance of the machine.

Step	Action
1	Enter magnet shape library
2	Enter iml_Vblock library
3	Select imb_Vblock_01E
4	Validate the magnet choice



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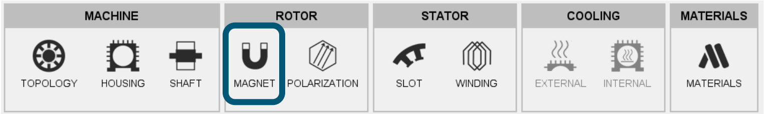
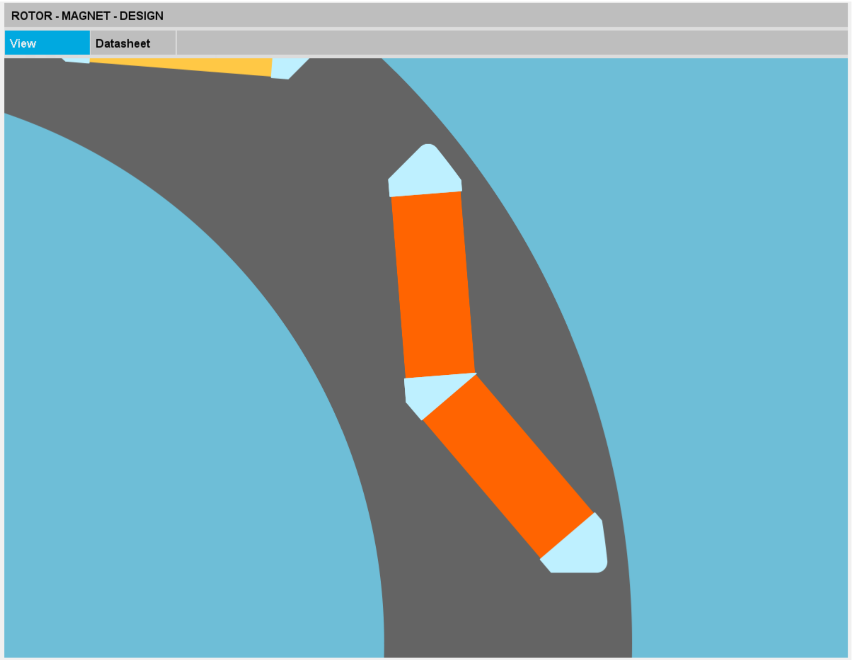
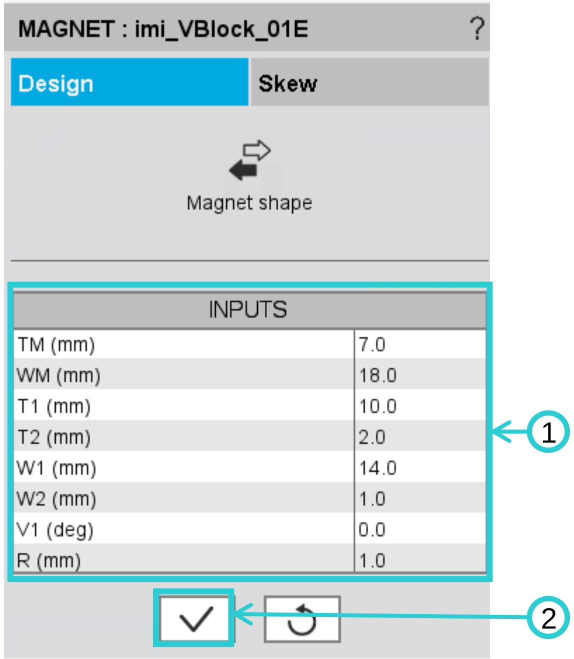
Magnet Geometry Definition



Step	Action
1	Fill in magnets dimensions
2	Validate





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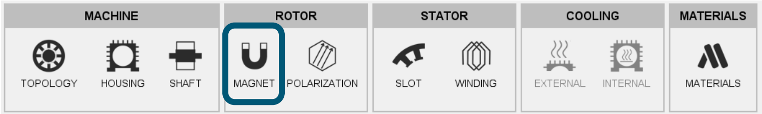
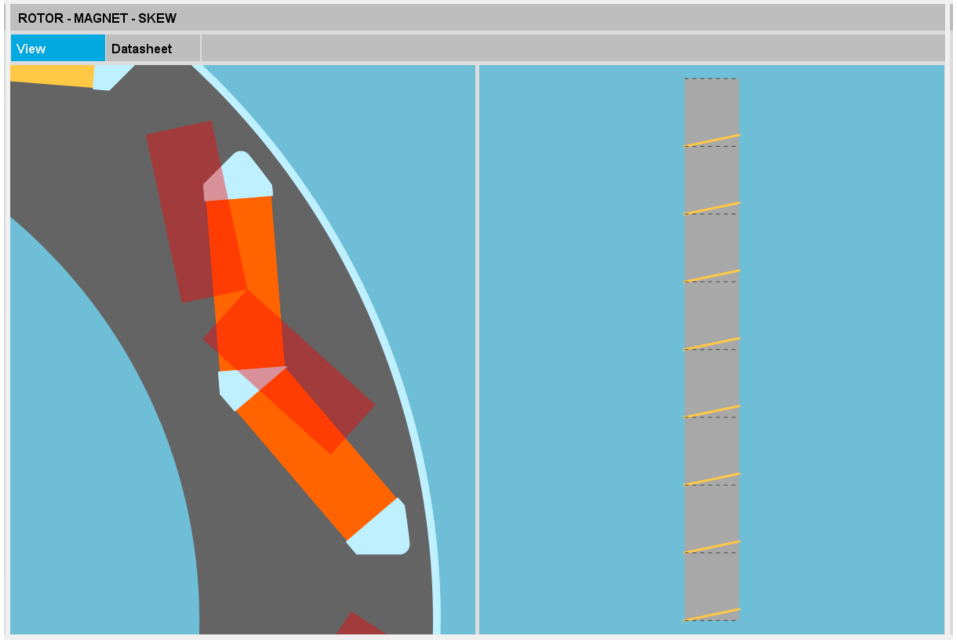
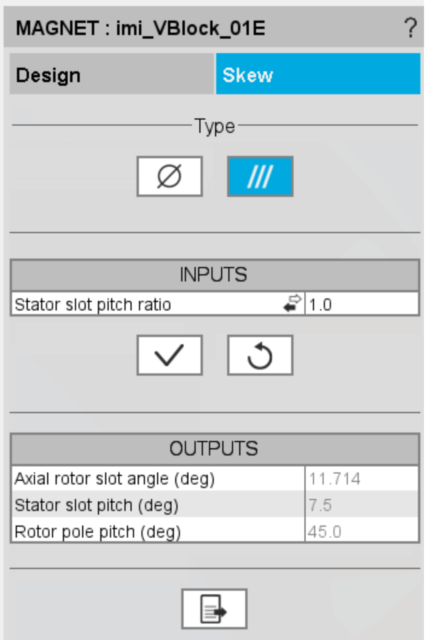
Rotor Skewing



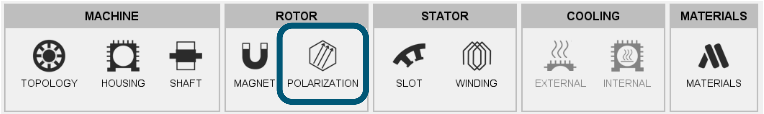
- Skew consists of skewing the rotor along its length. This reduces torque oscillation, vibration and noise. An exact choice of skewing is necessary because it can also reduce the average torque of the machine.



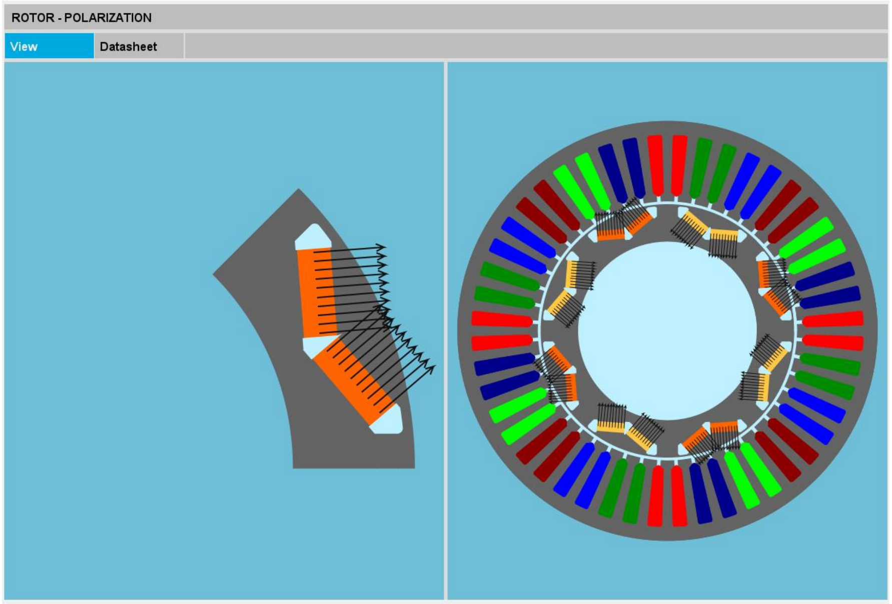


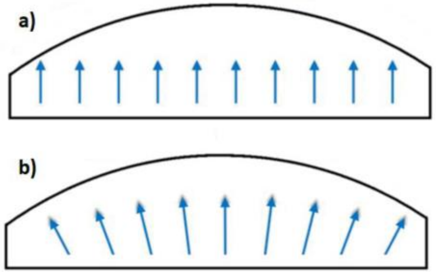
Slide put as an example to show the skewing option. There will be no skewing in the tutorial model (Do not define one.)

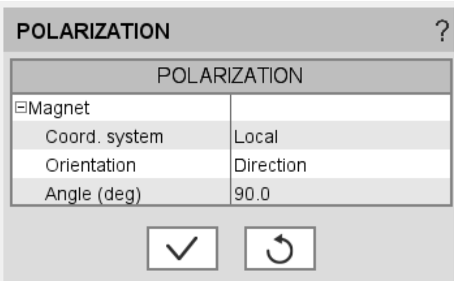
Magnet Polarization Definition



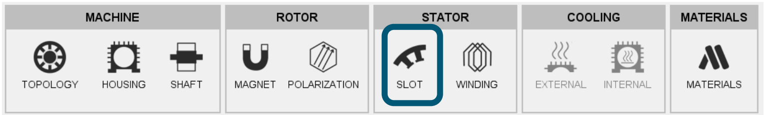
- The polarization of magnets corresponds to the direction given to their magnetization.
- In motors, this is mainly (a) parallel or (b) radial. The reference coordinates for adjusting the polarization can be global (center of the rotor) or local (localized coordinates depending on the topology of the magnet considered). The arrows make it possible to visualize the orientation of the resulting polarization.





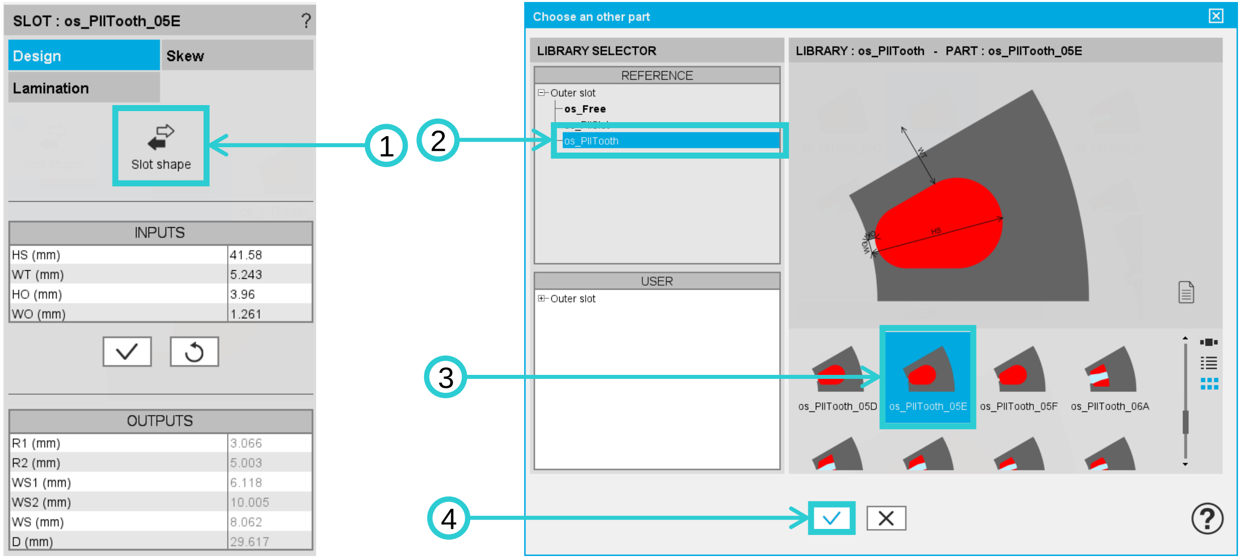


Slot Topology Definition

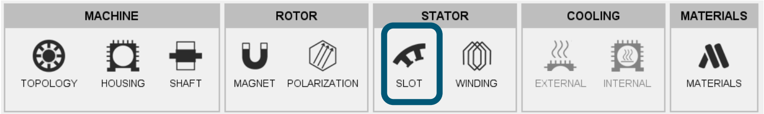


- The topology and the dimensions of the slots determine the quantity of copper present in the stator.
- This directly influences the amount of current flowing in the winding, which in turn produces the Magnetomotive Force (MMF) and the magnetic induction in the air gap.
- This also has an impact on the manufacturing costs of the stator (slot filling coefficients, etc.). Particular attention must be given to the slot (conductor entry, cogging torque).

Step	Action
1	Enter slot shape library
2	Enter os_PilTooth library
3	Select os_PilTooth_05E
4	Validate slot shape choice

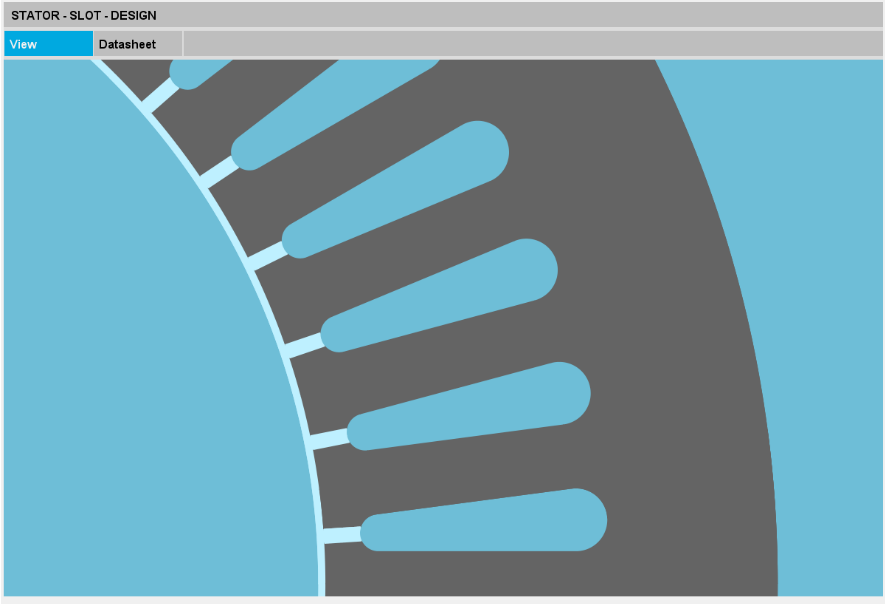


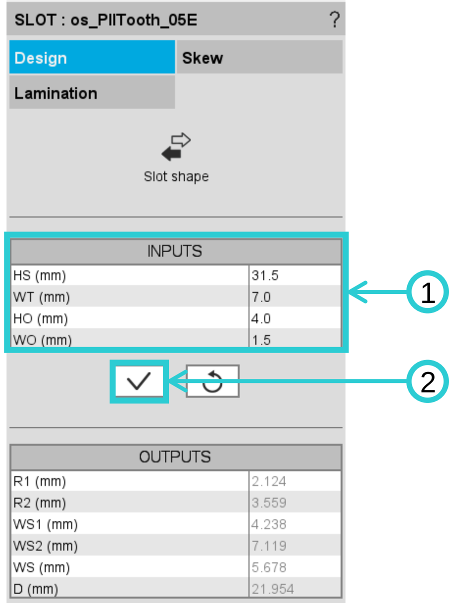
Slot Geometry Definition



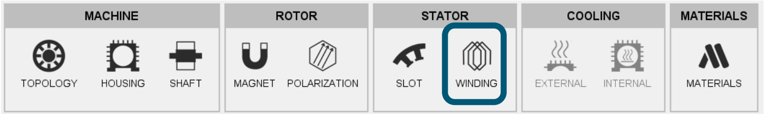
- The dimensions of the slots must be well chosen, so that it can contain all the electrical conductors necessary to achieve the performance of the motor.
- In FluxMotor, if the fill factor is greater than 100%, indicating that there are more conductors than the slot can accommodate, an error warning is given to the user.

Step	Action
1	Fill in slot dimensions
2	Validate

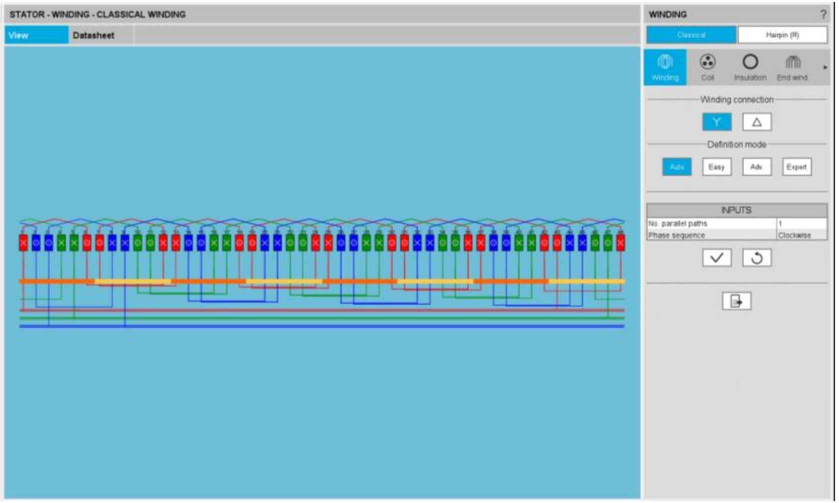


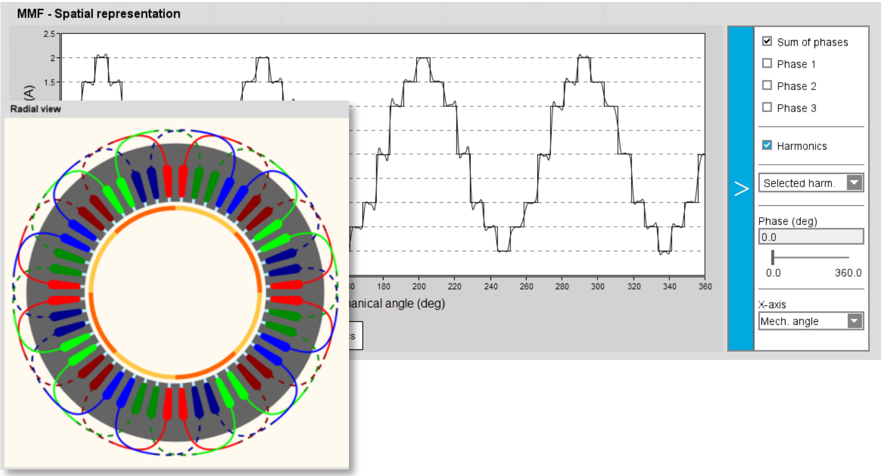


Winding Architecture



- The winding must be well defined to have a stator contribution to the magnetic induction, which is as sinusoidal as possible. An idea of this form can be observed by looking at the magnetomotive force (MMF) as well as its harmonic decomposition in the datasheet section.
- FluxMotor gives a feasible solution with the "Auto" mode. However, the user can define it more precisely if he feels comfortable with the other definition modes.





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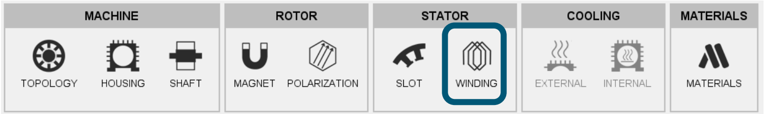
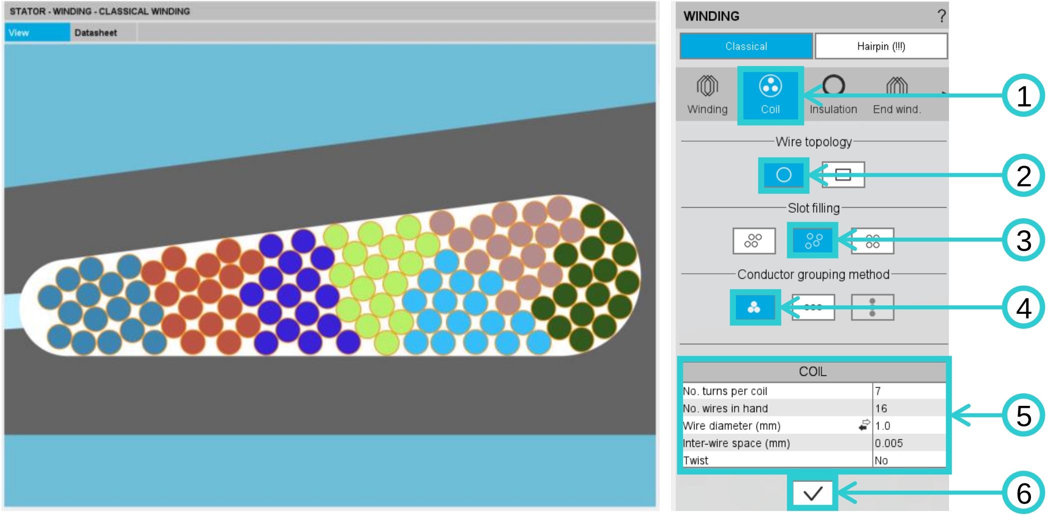
Winding : Electric Wire Definition

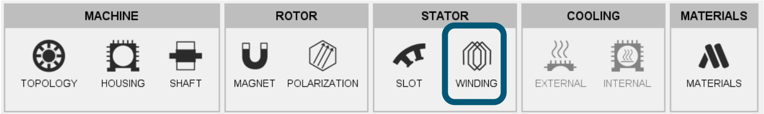


- This menu is used to define the slot filling according to the chosen conductor topology (circular or rectangular).
- The main input data to consider are the number of turns per coil, the number of elementary conductors (wires) and their dimensions.
- Several filling methods are available (ortho-cyclic, random or in layers) with also several methods of associating the wires forming a conductor (grouped, vertical or horizontal).

Step	Action
1	Enter coil editor context
2	Choose circular wire topology
3	Choose « random » filling methodology
4	Choose « grouped » conductor grouping method
5	Fill in insulation dimensions
6	Validate

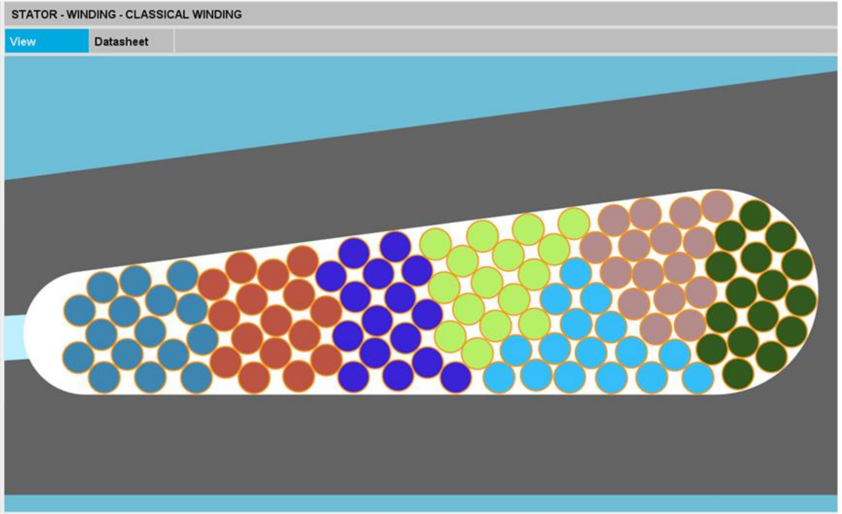


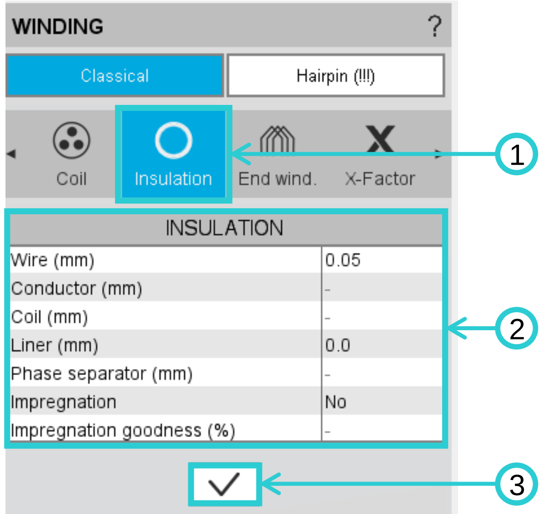
Winding : Wire Insulation Definition



- The electrical insulation of the conductors makes it possible to insulate the wires and prevent short circuits. It is also possible to add one on the slot periphery to block the electrical conductivity with the ferromagnetic parts.
- Impregnation consists of pouring resin into the slot, so that it is full and there is better heat exchange.

Step	Action
1	Enter insulation edition context
2	Fill in insulation dimensions
3	Validate





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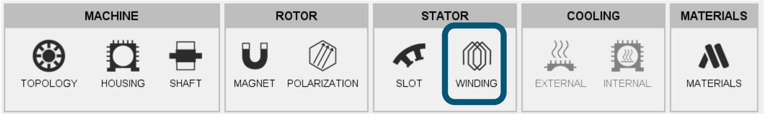
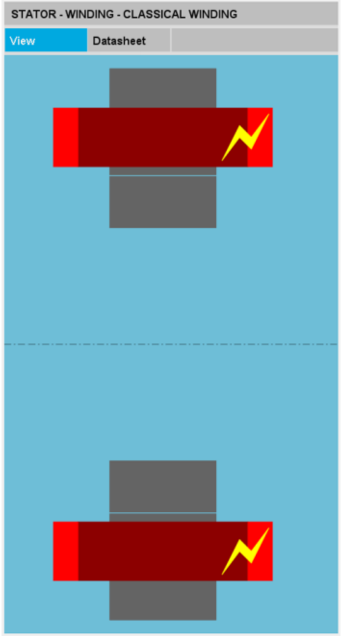
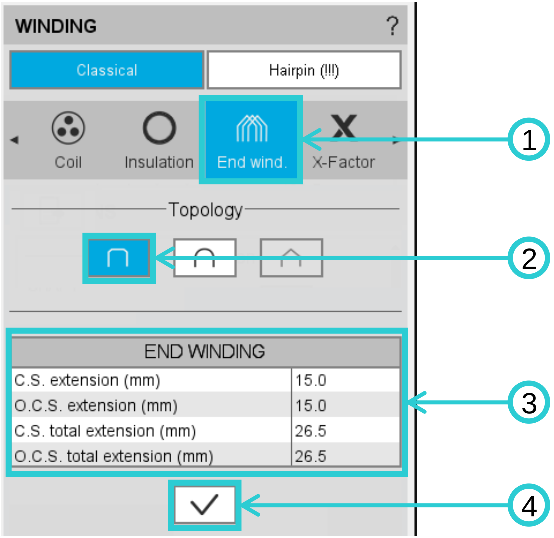
End Winding Definition



- The coil end windings are the link between the forward and return bundles of the coils. It impacts the resistances and inductances of the phases as well as the overall thermal behavior.
- These end windings also have an impact on the cost and size of the machine.

Step	Action
1	Enter End winding edition context
2	Choose « U Shape » topology
3	Fill in end winding dimensions
4	Validate





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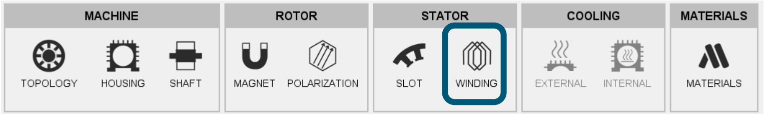
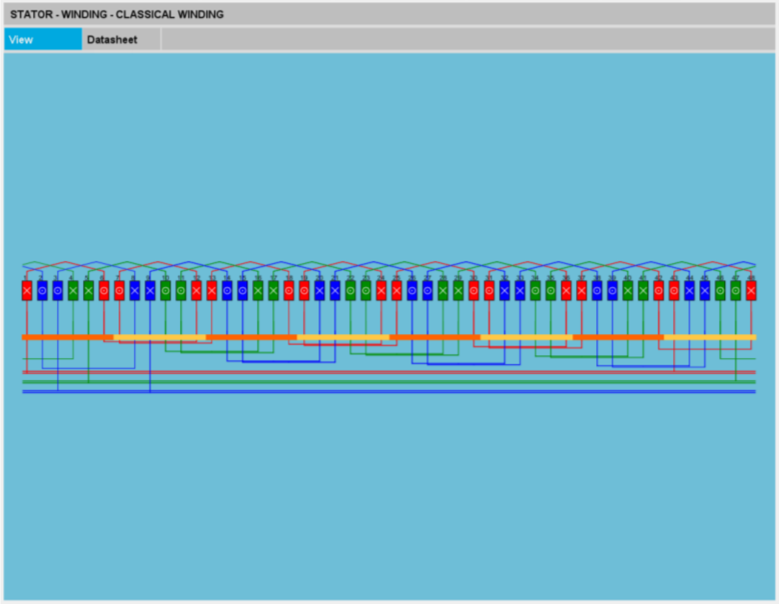
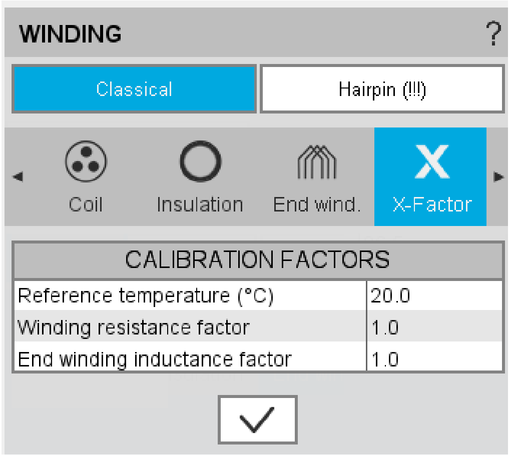
Winding : X-Factor



- This is a proportional coefficient allowing the values of the stator resistance and the inductance of the coil ends to be adjusted according to the values measured or calculated elsewhere.
- The evaluation of the resistances is made with reference to the temperature to be considered. Note that this temperature has no impact on the test environment of the machine.





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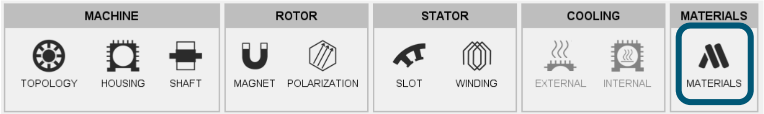
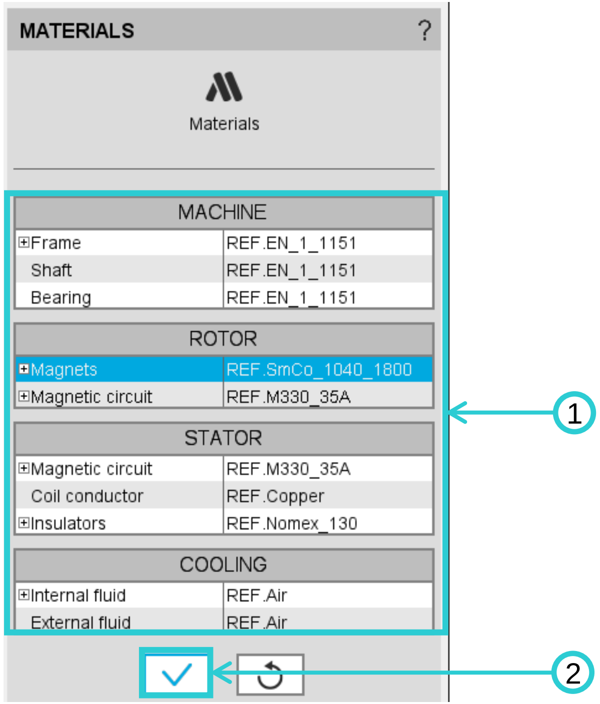
Materials Allocation





Step	Action
1	Fill in materials information
2	Validate

FluxMotor offers a catalog of materials. This covers major recurring needs, namely:

- Laminations
- Ferromagnetic materials to build the magnetic circuit of the rotor and stator
- Solid materials (steel, etc.) to build the magnetic circuit of the rotor and stator, if ferromagnetic, or other construction devices
- Magnets
- Electrical conductors (copper by default)
- Electrical insulators

It is also possible for the user to define one's own materials from the Materials module.

FLUXMOTOR
ANALYSIS AND AUTOMATIZED TESTS

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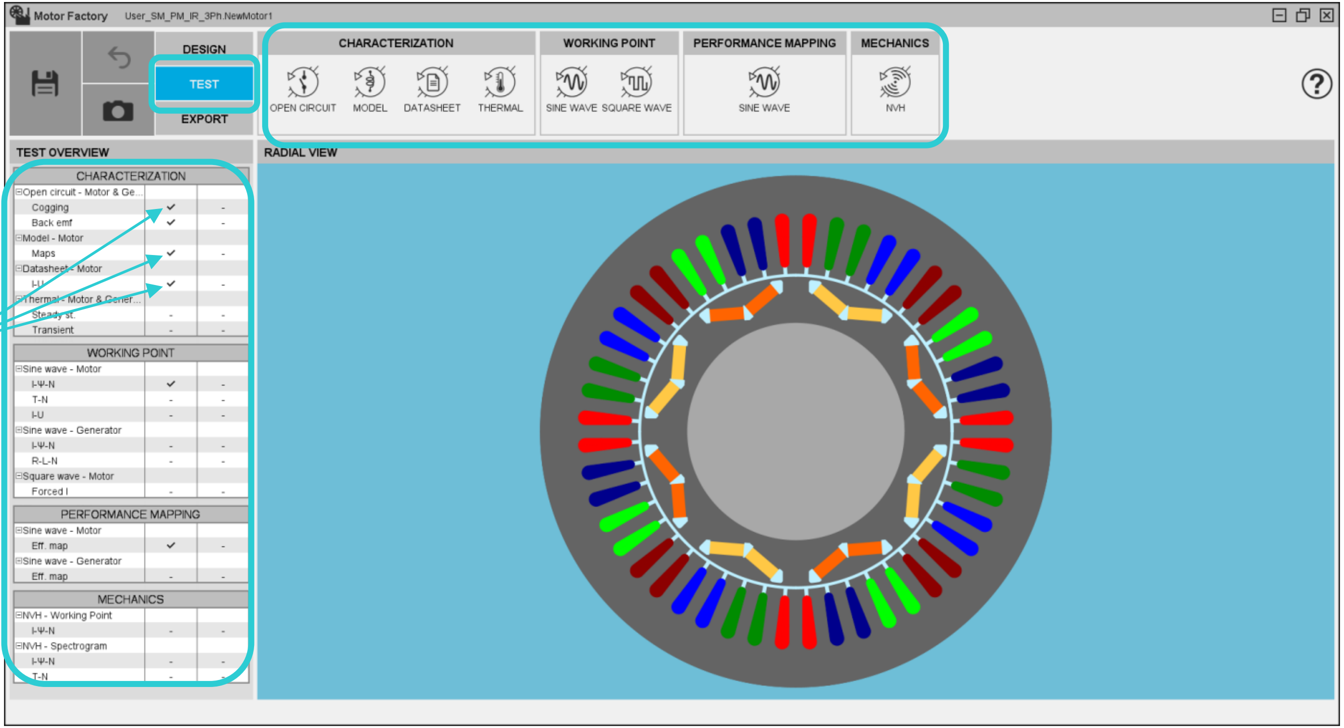
Introduction

Test interface

These checkmarks appear once the analysis has been carried out



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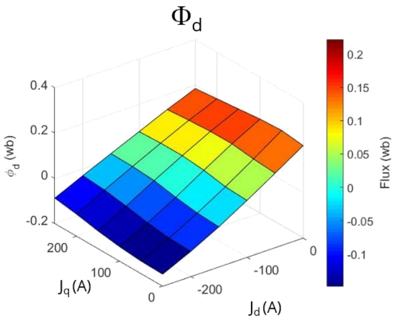
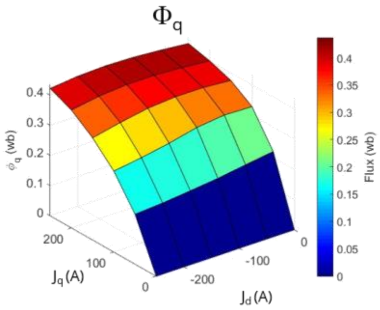
Motor Factory to Test Motors - Introduction

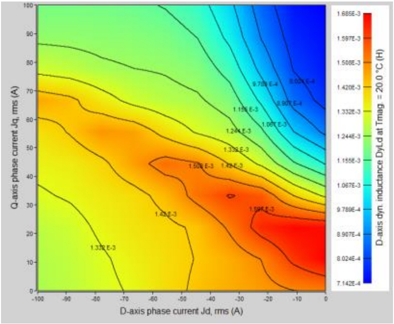
Internal computation procedure

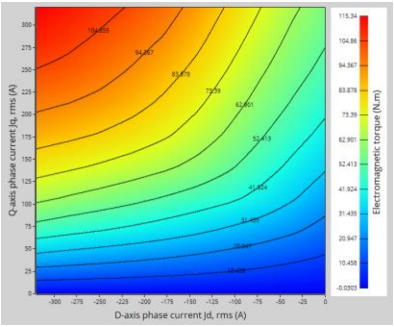
- Within Motor Factory, different calculation methods are integrated: Analytics, finite elements and optimizations.
- All tests are based on finite element modeling and calculations. The results are post-processed with the analytical approach and optimization processes.

$$T_{em,Park} = \frac{m}{2} \times p \times \left(\Phi_d \times J_q - \Phi_q \times J_d\right)$$



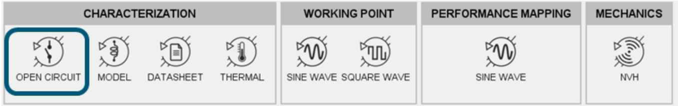




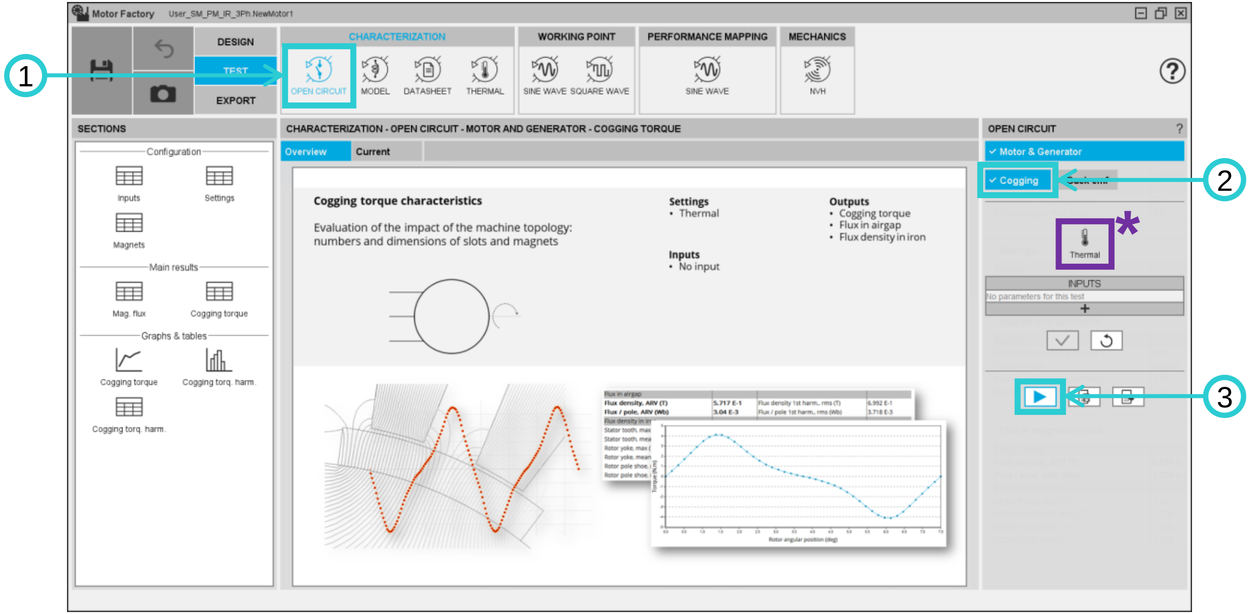


Open Circuit Analysis (Phase Current = 0)

Torque ripple and airgap magnetic flux density



- Thanks to this test, it is possible to evaluate the impact of the machine topology (slots and magnets - number and dimensions) on the characteristics of the cogging couple (magnitude and period).



***Magnet temperature can be modified for this test**

Step	Action
1	Choose Open Circuit test
2	Choose the cogging torque test
3	Launch computation

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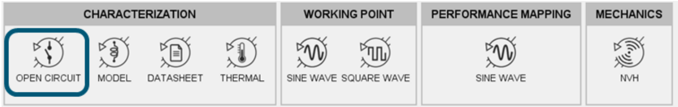
Open Circuit Analysis (Phase Current = 0)



Torque ripple and airgap magnetic flux density

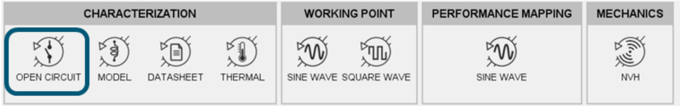
- Contrary, this test makes it possible to obtain the magnitude order of the magnetic induction induced by the magnets in the different parts of the motor. Here, we can observe maximum and average magnitudes.
- These values are useful for motor sizing, to prevent potential saturation of ferromagnetic materials.

Flux density in magnetic circuit over the period of analysis

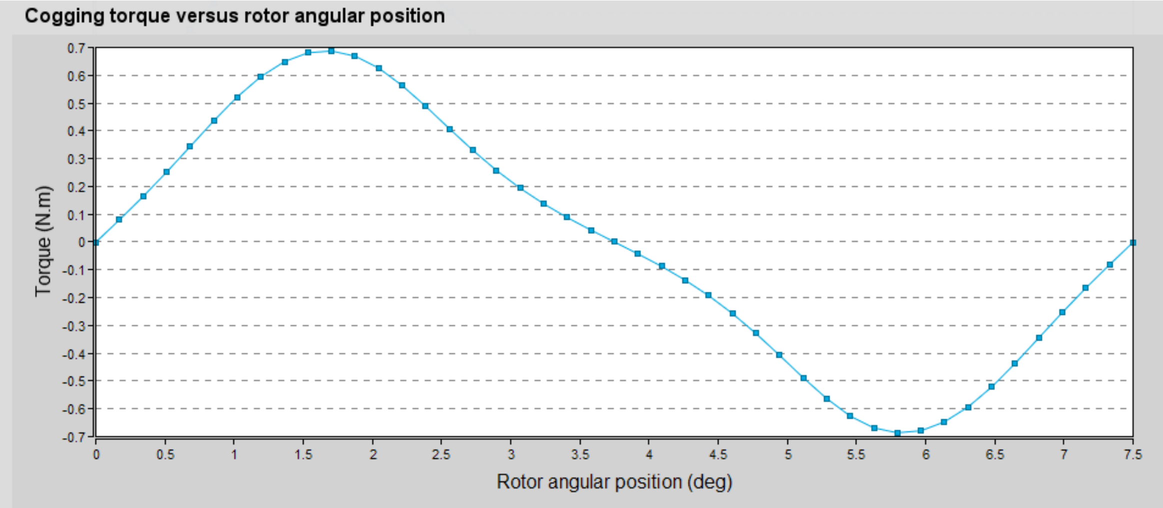
Flux density in iron					
Stator tooth, max (T)	1.08	Stator tooth, mean (T)	6.365 E-1		
Stator foot tooth, max (T)	1.326	Stator foot tooth, mean (T)	5.229 E-1		
Stator yoke, max (T)	1.117	Stator yoke, mean (T)	5.338 E-1		
Rotor yoke, max (T)	1.518	Rotor yoke, mean (T)	7.292 E-1		
Rotor web, max (T)	1.47	Rotor web, mean (T)	4.268 E-1		
Rotor bridge, max (T)	2.007	Rotor bridge, mean (T)	1.004		
Rotor pole shoe, max (T)	2.07	Rotor pole shoe, mean (T)	1.042		

Open Circuit Analysis (Phase Current = 0)

Torque ripple and airgap magnetic flux density

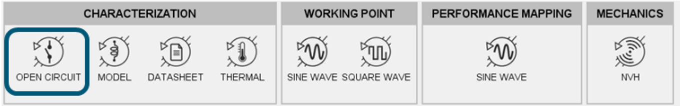


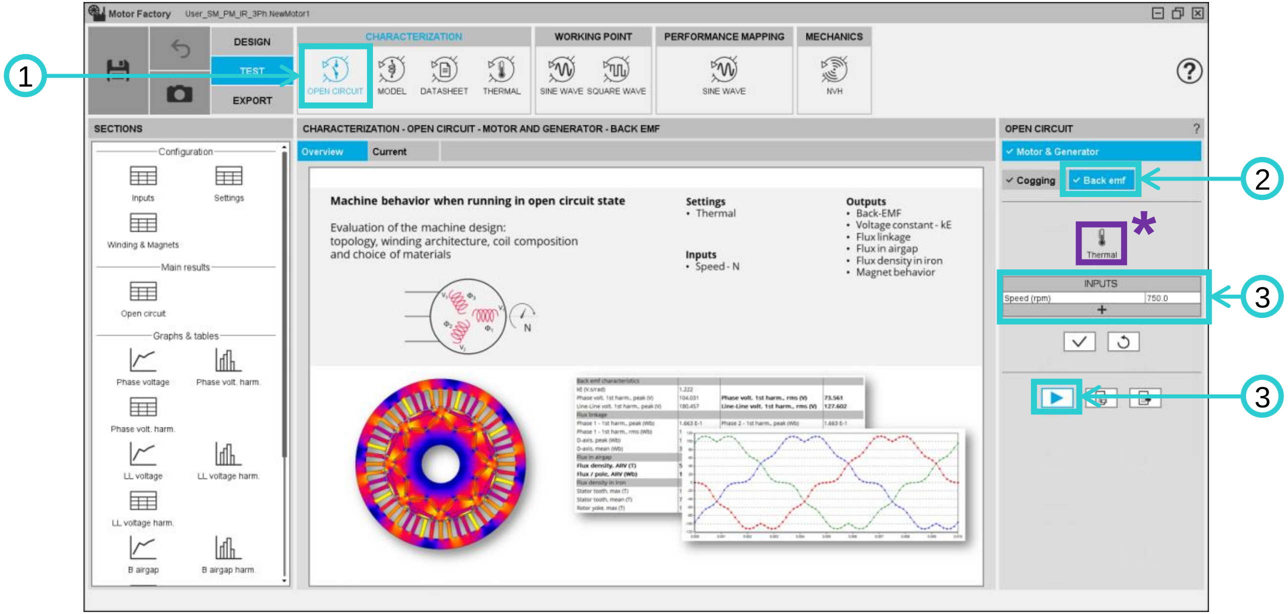
- The cogging torque is the motor torque at no current condition. It gives a vision of the tooth torque ripple that will be found in the torque ripple under load and which, potentially, play an important vibro-acoustic role.
- Torque ripple that are too high will require more current to be countered when starting the motor. If these are too high, it can be reduced by modifying the motor topology (more magnets or notches) and their dimensions or by adding skewing.



Open Circuit Analysis (Phase Current = 0)

Back-EMF Analysis



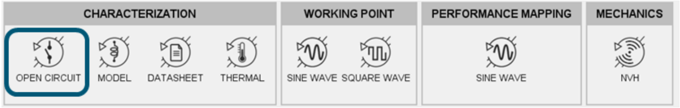


*Magnet temperature can be modified for this test

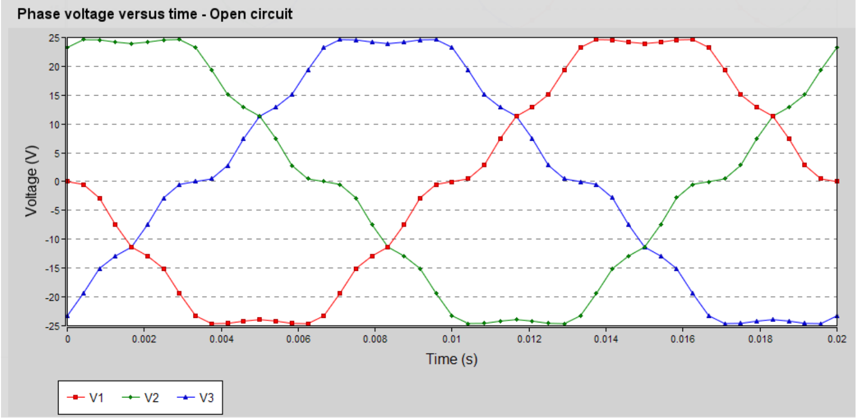
Step	Action
1	Choose Open Circuit test
2	Choose the BackEMF test
3	Select rotating speed
4	Launch computation

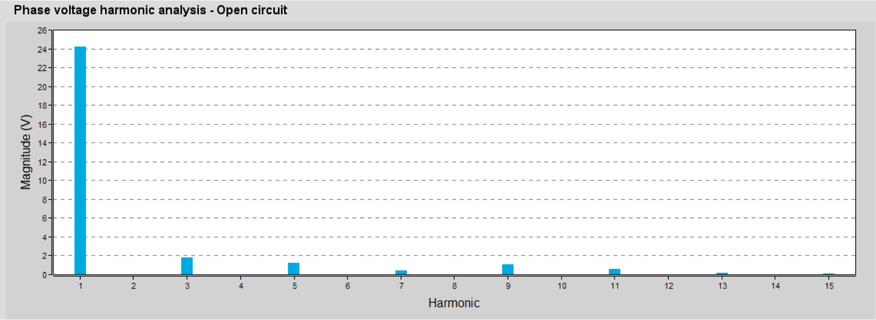
Open Circuit Analysis (Phase Current = 0)

Back-EMF Analysis



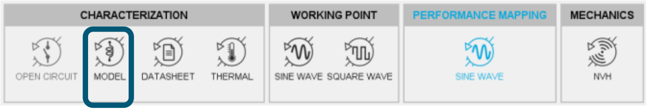
- Back EMF (Back-EMF) is the no-load voltage induced in the windings by the magnets.
- It gives an image of the magnetic state of the machine. It is particularly interesting to observe its harmonic content which gives an estimate of the excitations in the machine.



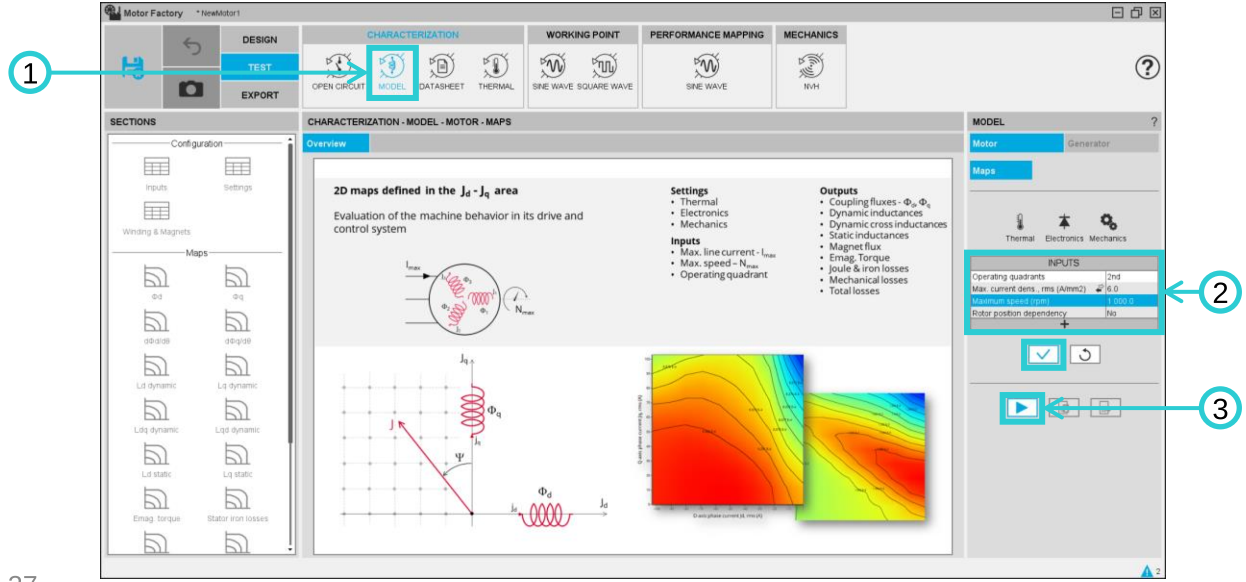


System Analysis of the Motor

Motor characterization



- This study calculates the parameters which make it possible to model the electric motor during the system analysis. The parameter maps are calculated and displayed in the Id, Iq plane.
- There are flux, inductances, torque but also iron losses, Joule losses, etc. These results make it possible to define the size of the motor driving system.



Step	Action
1	Choose characterization model test
2	Fill in the computation parameters
3	Launch computation

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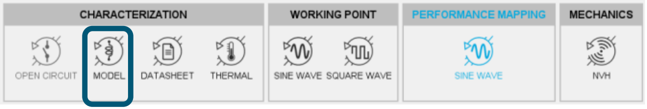
System Analysis of the Motor

Motor characterization



- The parameters given in this table make it possible to produce an equivalent motor system model. This equation model is used to calculate the voltages at the terminals of the machine and to represent its operation.
- It is possible to calculate these quantities as a function of the temperature, by considering the variations of Br of the magnets.
- Determination of the characteristics of magnets and windings:

Winding and Magnet characteristics

Winding					
Winding connection	Wye	Winding resistance factor	1.0		
Winding temperature (°C)	20.0				
Phase resistance (Ω)	2.653 E-2	Line-Line resistance (Ω)	5.305 E-2	End winding resistance (Ω)	1.884 E-2
Winding straight part temperature (°C)	20.0	C.S. end winding temperature (°C)	20.0	O.C.S. end winding temperature (°C)	20.0
Winding straight part resistance (Ω)	7.683 E-3	C.S. end winding resistance (Ω)	1.081 E-2	O.C.S. end winding resistance (Ω)	8.032 E-3
Magnets					
Magnet temperature Tmag (°C)	20.0				
Magnet name	Magnet	Material name	REF.SmCo_1...	Material reference temp. Tref (°C)	20.0
Remanent induction at Tref (T)	1.04	Intrinsic coercive field at Tref (A/m)	1.8 E6	Relative permeability at Tref	1.04
Remanent induction at Tmag (T)	1.04	Intrinsic coercive field at Tmag (A/m)	1.8 E6	Relative permeability at Tmag	1.04

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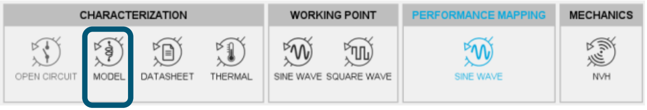
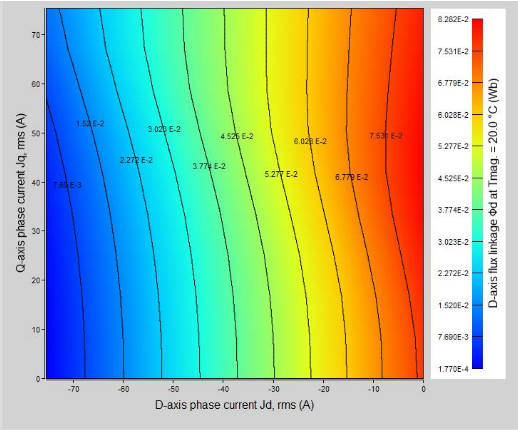
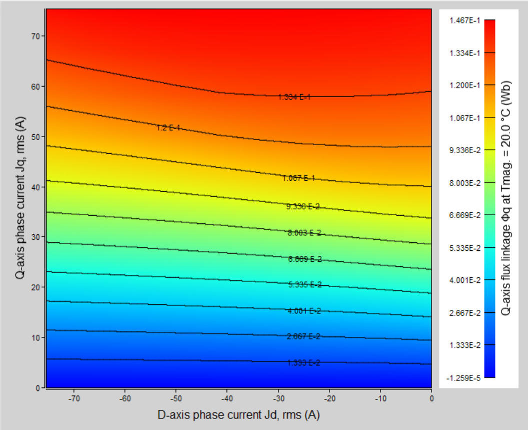
System Analysis of the Motor

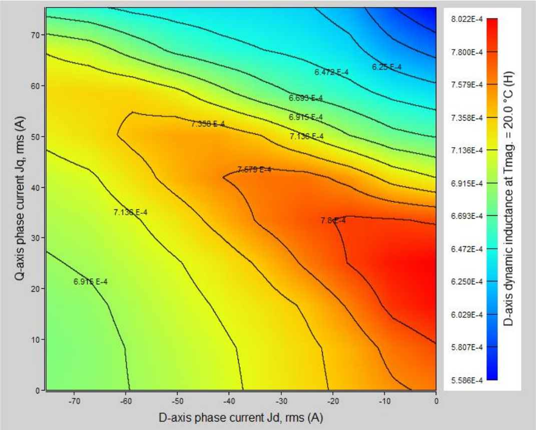
Flux and Inductances maps



- Representation of magnetic induction, static and dynamic inductances as a function of currents Id and Iq.
- These data make it possible to calculate the motor efficiency maps which will be presented later.







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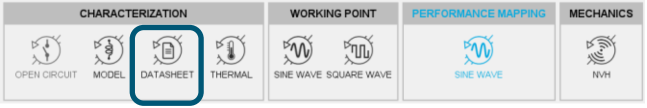
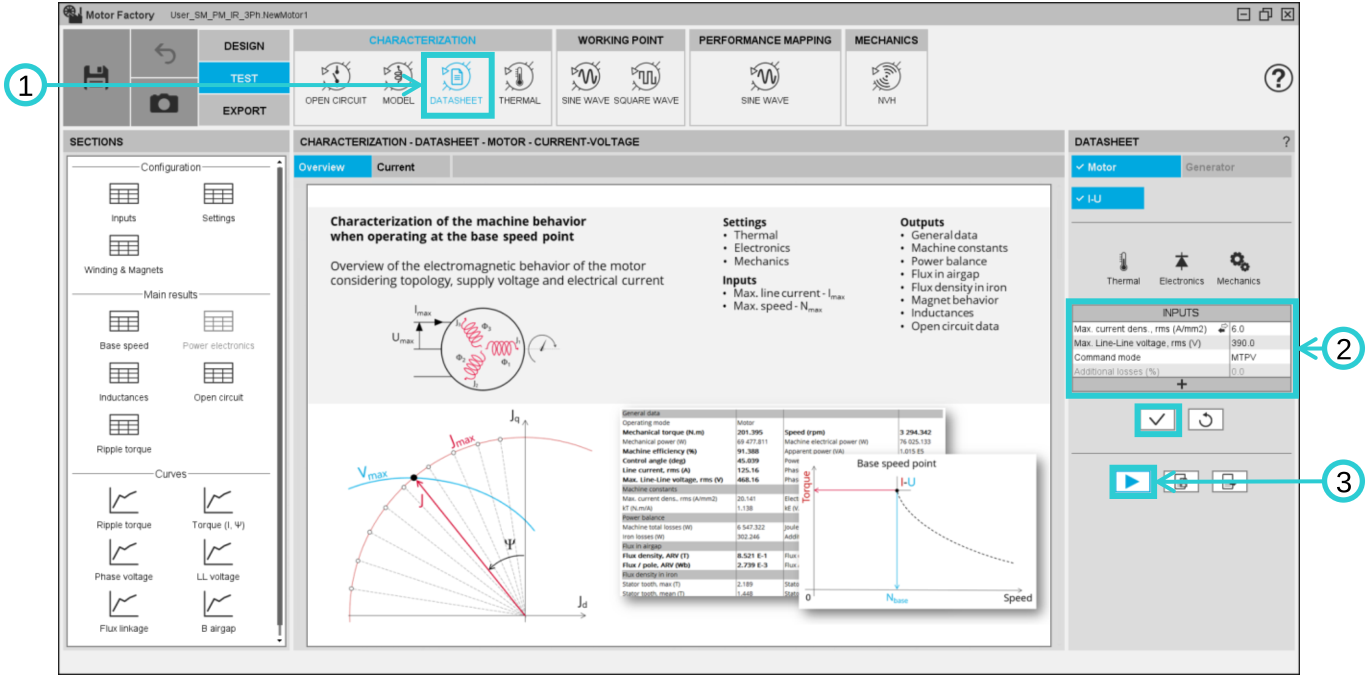
Motor Datasheet

Characterization of the motor at the nominal working point





Step	Action
1	Choose characterization datasheet test
2	Fill in computation parameters
3	Launch computation

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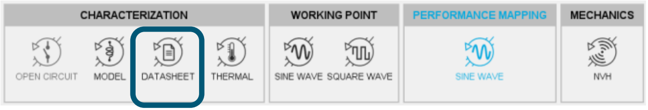
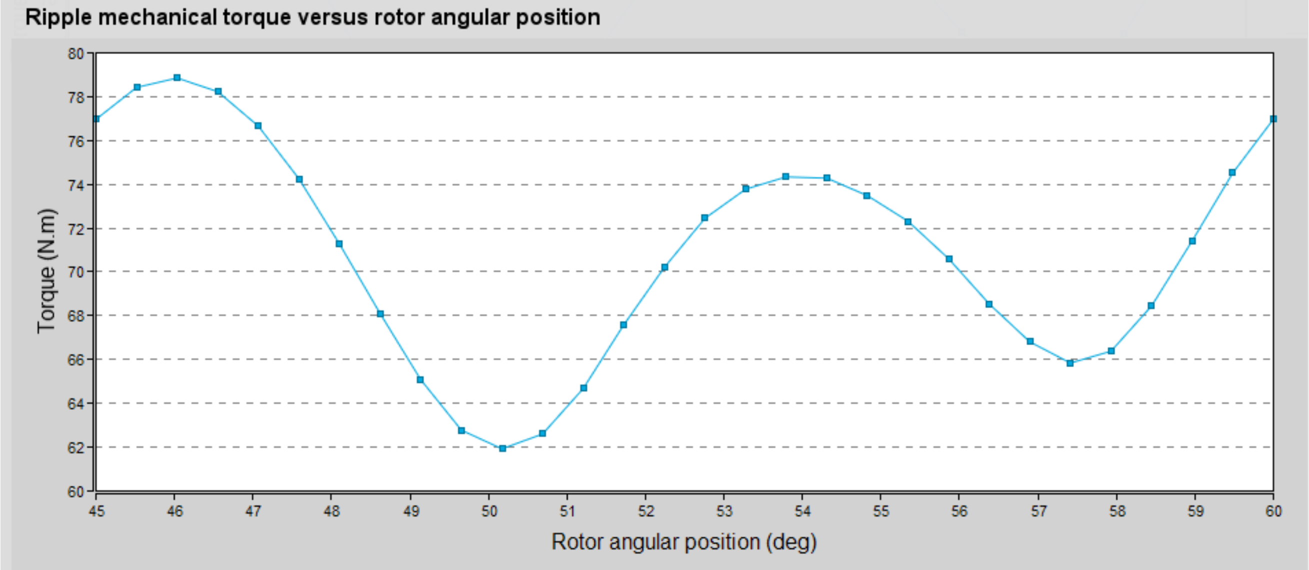
Motor Datasheet



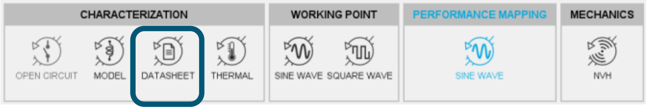
Motor torque for a given current and voltage as a function of the rotor position

- This is the instantaneous torque as a function of the angular position of the rotor.
- The average torque of the motor is a main criterion of the specifications.

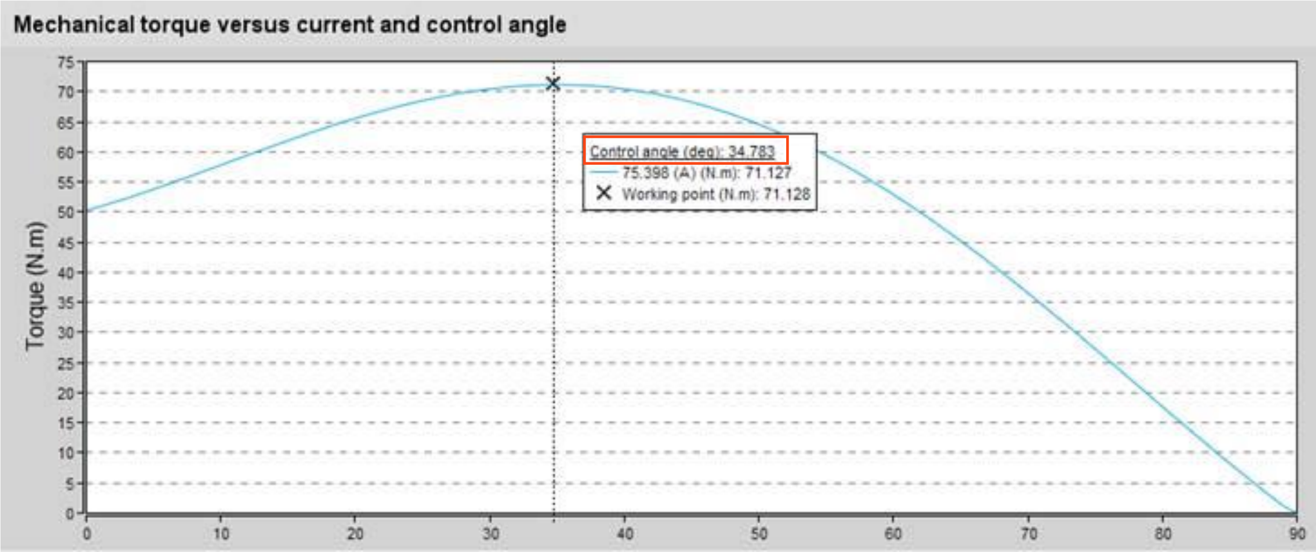


Motor Datasheet

Average torque as a function of control angle

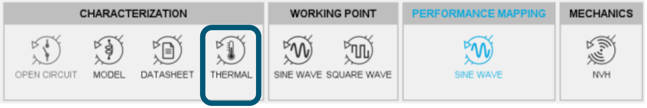


- The control angle corresponds to the phase difference between the resulting flux and the rotor flux (magnet flux).
- Depending on the saliency of the machine and for a given current value, it is possible to choose the optimum operating point in terms of torque. For example:

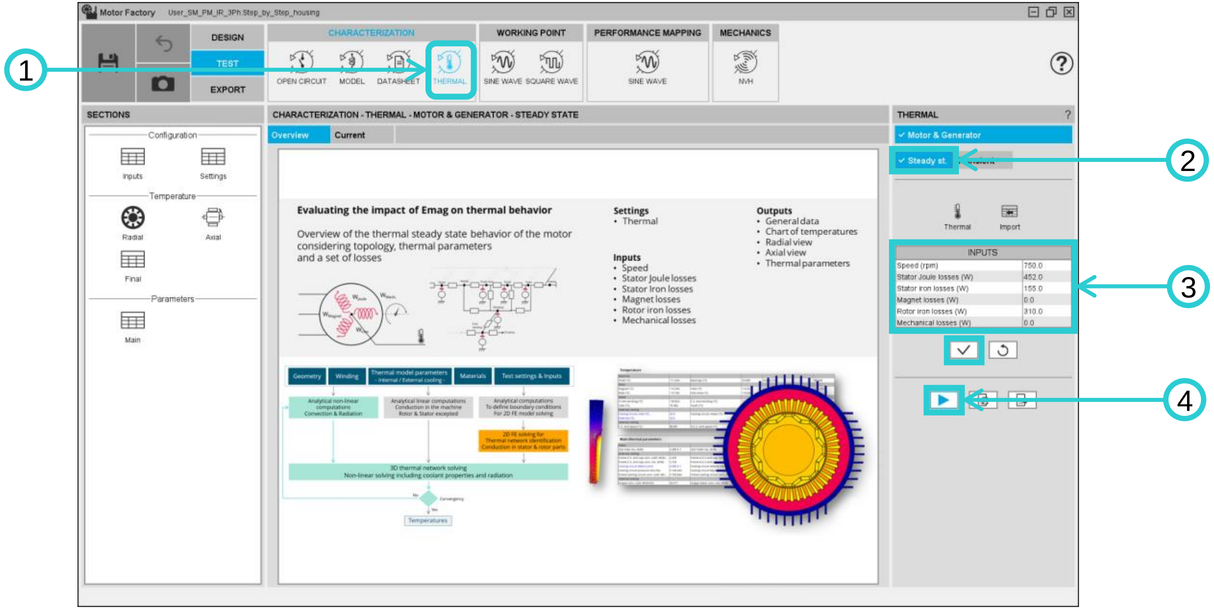


Thermal Characterization Test

Steady State analysis



This analysis gives an overview of the temperature that the various parts of the motor will reach at steady state for given thermal parameters and a set of losses.



Step	Action
1	Choose thermal test
2	Choose steady state test
3	Fill in computation parameters
4	Launch computation

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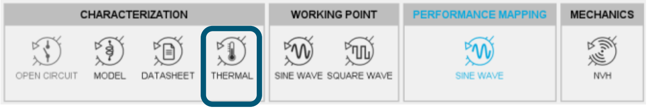
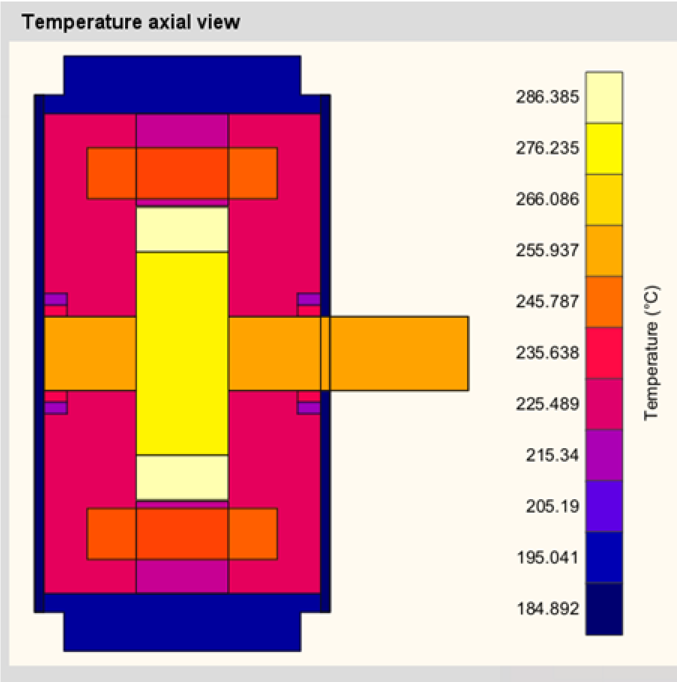
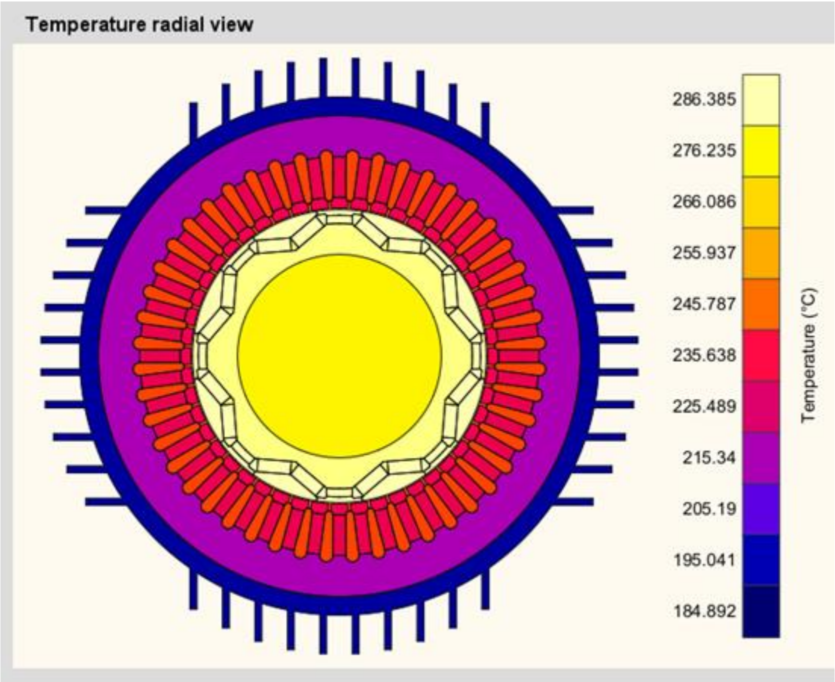
Thermal Analysis

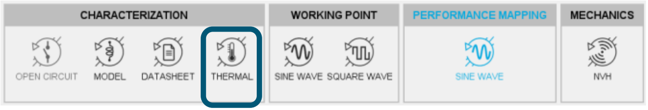




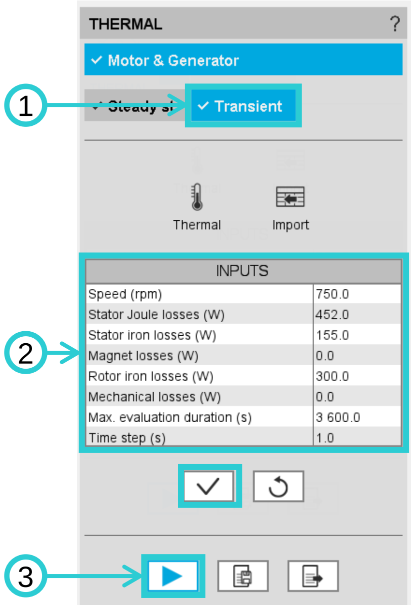


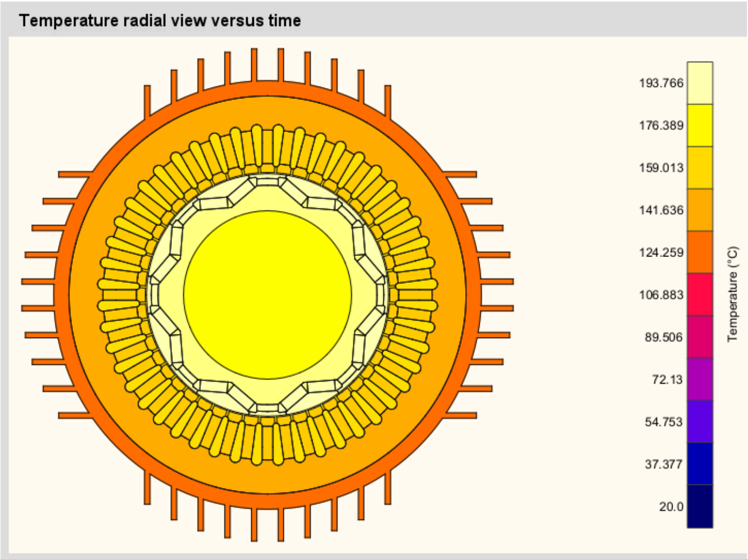
Thermal Characterization Test

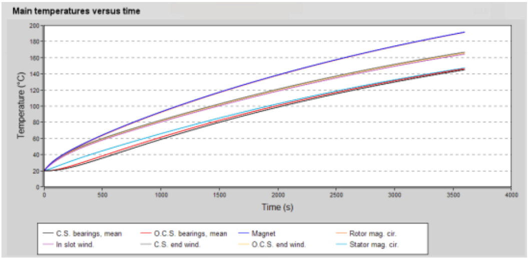
Transient analysis



This analysis gives an overview of the evolution of the temperature of the various parts of the motor during a transient computation for given thermal parameters and a set of losses.



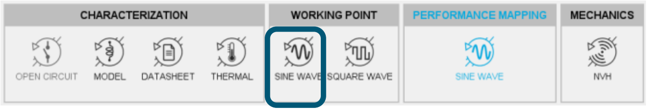




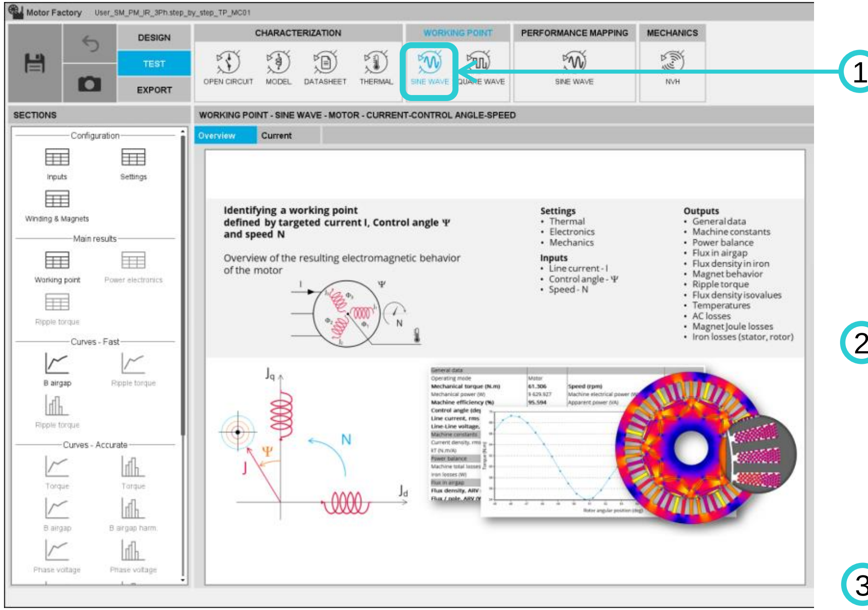
Step	Action
1	Choose transient test
2	Fill in computation parameters
3	Launch computation

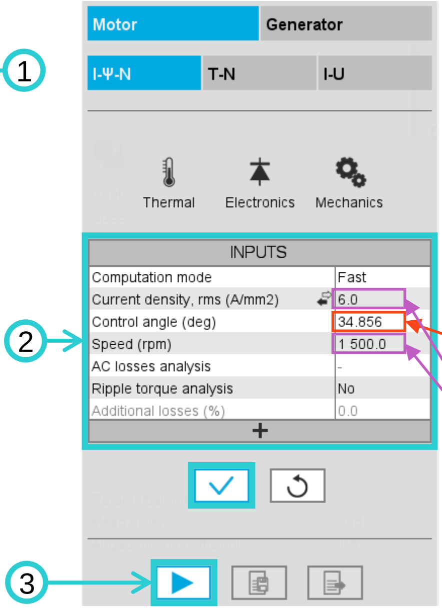
Working Point Analysis

With Sine Wave currents



This study gives a good estimate of the magnetic and electrical quantities as well as the losses of the machine for an operating point defined by the user for a sinusoidal power supply.





Step	Action
1	Choose working point sine wave test
2	Fill in the parameters
3	Launch computation

Value found in Datasheet test

Value from specifications

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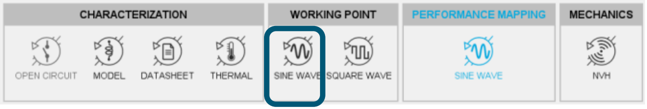
Working Point Analysis

With Sine Wave currents



Interesting results (and usefulness):

1. General results characterizing the operating point
2. Power balance, losses, efficiency
3. Magnetic induction and flux in the air gap (generator of electromagnetic forces)
4. Order of magnitude of induction in the active parts of the magnetic circuit of the motor (prevent materials saturation)
5. Estimation of magnet demagnetization
6. Magnetic induction in the air gap in one pole

Machine performance - Working point

1	General data					
	Operating mode	Motor				
	Mechanical torque (N.m)	**71.89**	**Speed (rpm)**	**1 500.0**	Electrical frequency (Hz)	100.0
	Mechanical power (W)	11 292.415	Machine electrical power (W)	11 816.484	Machine total losses (W)	524.068
	Machine efficiency (%)	**95.565**	Apparent power (VA)	14 802.511	Reactive power (VAr)	8 915.439
	Control angle (deg)	**34.856**	Power factor	7.983 E-1	Phase angle (deg)	37.034
	Line current, rms (A)	**75.398**	Phase current, rms (A)	75.398		
	Line-Line voltage, rms (V)	**113.348**	Phase voltage, rms (V)	65.441		
	Machine constants					
	Current density, rms (A/mm2)	6.0	Electrical loading, rms (A/m)	50 400.0	Power density (W/kg)	451.776
	kT (N.m/A)	6.742 E-1				
2	Power balance					
	Machine total losses (W)	524.068				
	Joule losses (W)	452.382	Stator Joule losses (W)	452.382		
	Total Iron losses (W)	71.687	Stator Iron losses (W)	71.687		
	Mechanical losses (W)	0.0	Additional losses (W)	0.0		
3	Flux in airgap					
	Flux density, ARV (T)	**7.548 E-1**	Flux density 1st harm., rms (T)	8.401 E-1	Flux density, peak (T)	1.539
	Flux / pole, ARV (Wb)	**2.359 E-3**	Flux / pole 1st harm., rms (Wb)	2.626 E-3	Flux / pole, peak (Wb)	4.81 E-3
4	Flux density in iron					
	Stator tooth, max (T)	1.747	Stator tooth, mean (T)	1.198		
	Stator foot tooth, max (T)	2.048	Stator foot tooth, mean (T)	1.044		
	Stator yoke, max (T)	1.685	Stator yoke, mean (T)	9.878 E-1		
	Rotor yoke, max (T)	1.732	Rotor yoke, mean (T)	1.093		
	Rotor web, max (T)	1.888	Rotor web, mean (T)	1.611		
	Rotor bridge, max (T)	2.366	Rotor bridge, mean (T)	1.638		
	Rotor pole shoe, max (T)	2.32	Rotor pole shoe, mean (T)	1.245		
5	Magnet behavior					
	Magnet name	Magnet	Material name	REF.SmCo_1...		
	Flux density, mean (T)	8.29 E-1	Coercive field 50% (A/m)	9.0 E5	Demagnetization rate < CF50 (%)	100.0
	Magnetic field strength, mean (A/m)	1.705 E5	Coercive field 90% (A/m)	1.62 E6	Demagnetization rate > CF90 (%)	0.0

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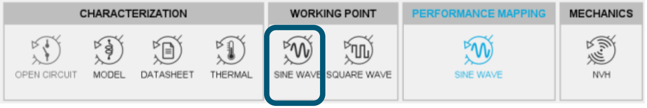
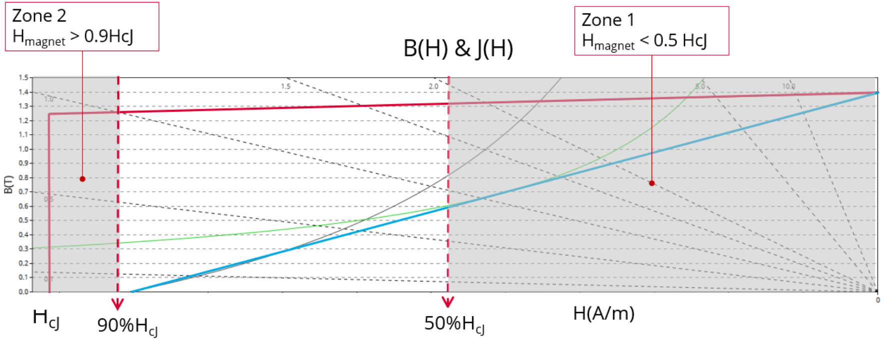
Working Point Analysis

Estimation of magnet demagnetization



The coercive field H_{cj} measures the magnetic field necessary to cancel the induction of a magnet. If the magnet works in zone 1 ($H<0.5H_{cj}$), there is no risk that it will demagnetize.

Magnet behavior					
Magnet name	Magnet	Material name	REF.SmCo_1...		
Flux density, mean (T)	8.063 E-1	Coercive field 50% (A/m)	9.0 E5	Demagnetization rate < CF50 (%)	100.0
Magnetic field strength, mean (A/m)	1.868 E5	Coercive field 90% (A/m)	1.62 E6	Demagnetization rate > CF90 (%)	0.0



Label	Symbol	Tooltip, note, formula
Magnet name	-	
Material name	-	When several kinds of magnet materials are considered, the magnet behavior is defined for each kind of magnet material
Flux density, mean	B_{magnet}	Flux density, mean value. Mean value of flux density computed in all the magnets.
Magnetic field strength, mean	H_{magnet}	Magnetic field strength, mean value. Mean value of the magnetic field computed in all the magnets.
Coerc.Field 50%	50%HcJ	Coercive field 50%. $50\%HcJ = 0.5 \times HcJ$ = limit to define Zone 1 for demagnetization analysis.
Coerc.Field 90%	90%HcJ	Coercive field 90%. $90\%HcJ = 0.9 \times HcJ$ = limit to define Zone 2 for demagnetization analysis
Demag. rate < CF50	$D_{emag}50$	Percentage of magnet area in Zone 1 (where maximum magnetic field, absolute value, is lower than $50\%HcJ = 0.5 \times HcJ$)
Demag. rate > CF90	$D_{emag}90$	Percentage of magnet area in Zone 2 (where maximum magnetic field, absolute value, is greater than $90\%HcJ = 0.9 \times HcJ$

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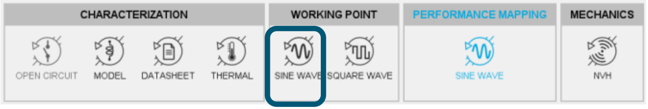
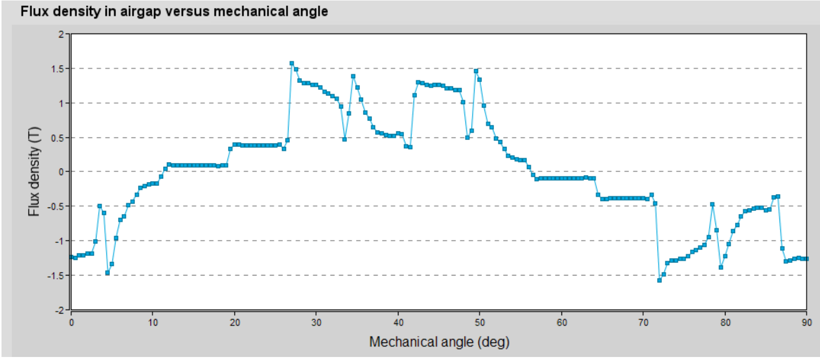
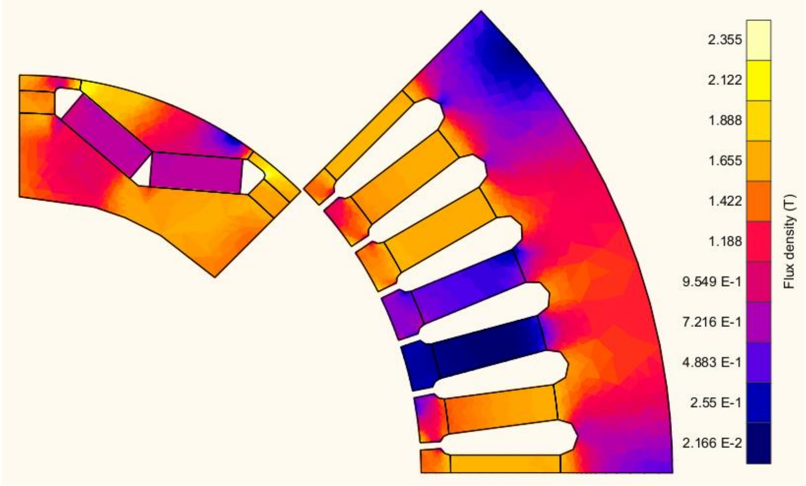
Working Point Analysis

Magnetic induction in the air gap for one pole

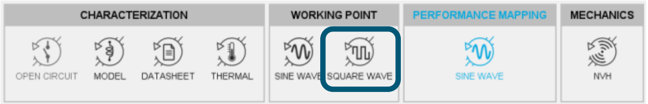




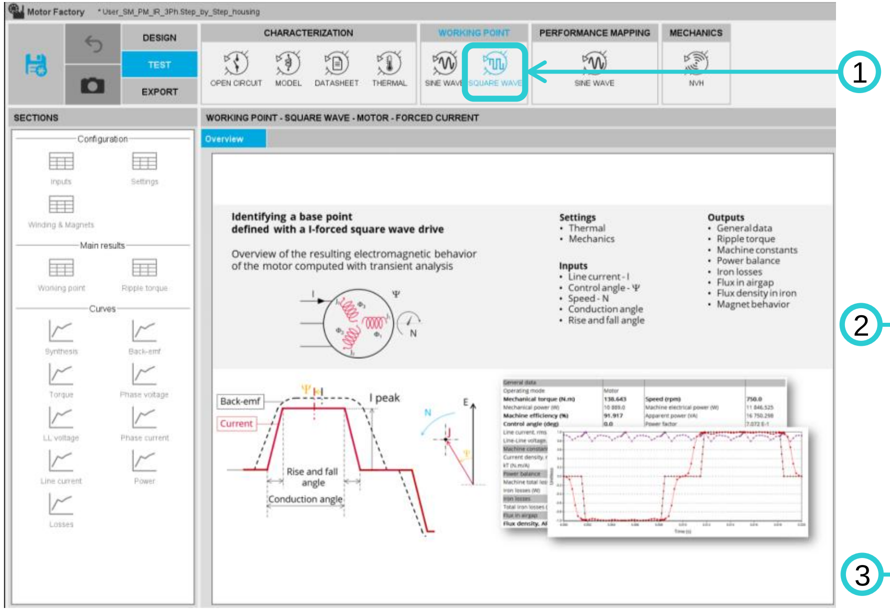


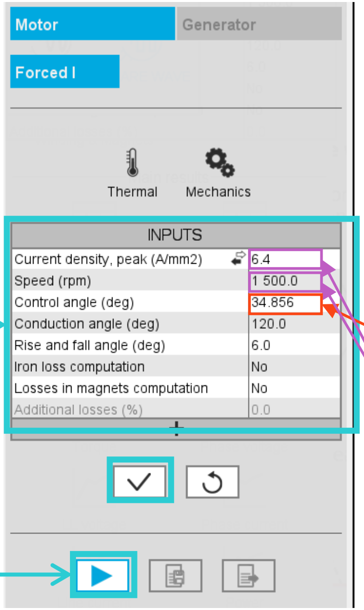
Working Point Analysis

With Square Wave currents



This study gives a good estimate of the magnetic and electrical quantities as well as the losses of the machine for an operating point defined by the user for a square power supply.





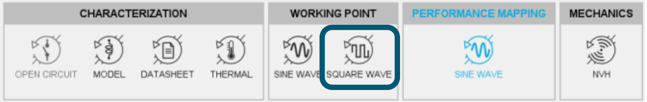
Step	Action
1	Choose working point square wave test
2	Fill in the parameters
3	Launch computation

Value found in Datasheet test

Value from specifications

Working Point Analysis

With Square Wave currents



Machine performance - Working point

General data					
Operating mode	Motor				
Mechanical torque (N.m)	**56.325**	**Speed (rpm)**	**1 500.0**	Electrical frequency (Hz)	100.0
Mechanical power (W)	8 847.572	Machine electrical power (W)	9 185.169	Machine total losses (W)	337.597
Machine efficiency (%)	**96.325**	Apparent power (VA)	27 843.098		
Control angle (deg)	**34.856**	Power factor	3.299 E-1		
Line current, rms (A)	65.53	Phase current, rms (A)	65.53	**Line current, peak (A)**	**80.425**
Line-Line voltage, rms (V)	243.813	Phase voltage, rms (V)	141.63	**Line-Line voltage, peak (V)**	**1 151.774**
Machine constants					
Current density, rms (A/mm2)	5.215	Electrical loading, rms (A/m)	43 803.681	Power density (W/kg)	353.965
kT (N.m/A)	7.003 E-1	kE (V.s/rad)	6.119 E-1		
Power balance					
Machine total losses (W)	337.597	Joule losses (W)	337.597	Losses in magnet (W)	0.0
Iron losses (W)	0.0	Additional losses (W)	0.0	Mechanical losses (W)	0.0
Iron losses					
Total iron losses (W)	0.0	Stator iron losses (W)	0.0	Rotor iron losses (W)	0.0
Flux in airgap					
Flux density, ARV (T)	**6.622 E-1**	Flux density 1st harm., rms (T)	8.906 E-1	Flux density, peak (T)	1.298
Flux / pole, ARV (Wb)	**2.07 E-3**	Flux / pole 1st harm., rms (Wb)	2.784 E-3	Flux / pole, peak (Wb)	4.057 E-3
Flux density in iron					
Stator tooth, max (T)	1.773	Stator tooth, mean (T)	1.155		
Stator foot tooth, max (T)	2.101	Stator foot tooth, mean (T)	9.703 E-1		
Stator yoke, max (T)	1.758	Stator yoke, mean (T)	8.767 E-1		
Rotor yoke, max (T)	1.74	Rotor yoke, mean (T)	1.003		
Rotor web, max (T)	1.86	Rotor web, mean (T)	1.403		
Rotor bridge, max (T)	2.298	Rotor bridge, mean (T)	1.58		
Rotor pole shoe, max (T)	2.295	Rotor pole shoe, mean (T)	1.233		
Magnet behavior					
Magnet name	Magnet	Material name	REF.SmCo_1...		
Flux density, mean (T)	8.484 E-1	Coercive field 50% (A/m)	9.0 E5	Demagnetization rate < CF50 (%)	100.0
Magnetic field strength, mean (A/m)	1.533 E5	Coercive field 90% (A/m)	1.62 E6	Demagnetization rate > CF90 (%)	0.0

Ripple mechanical torque

Working point					
Mechanical torque (N.m)	56.325				
Ripple mech. torque, pk-pk (N.m)	17.203	Ripple mech. torque +- vs avg (%)	30.542	Ripple torque period (deg)	15.0

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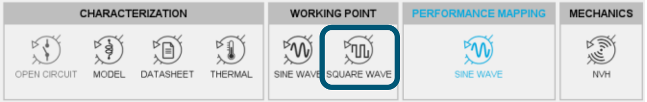
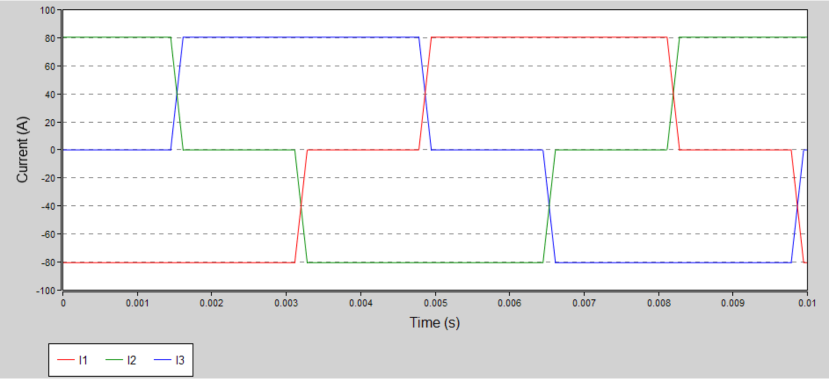
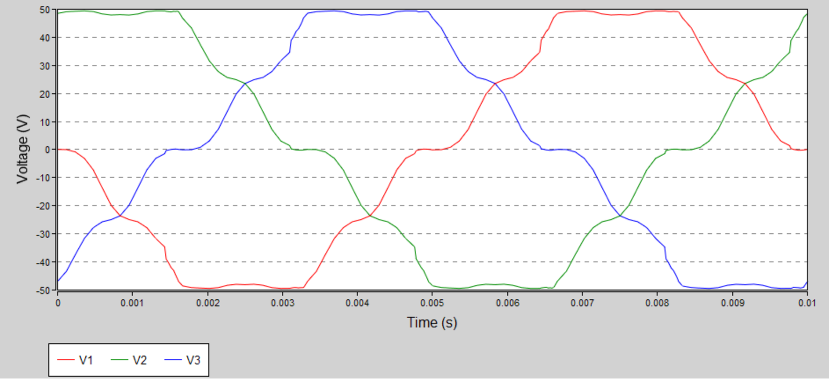
Working Point Analysis

With Square Wave currents

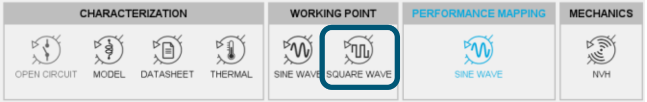


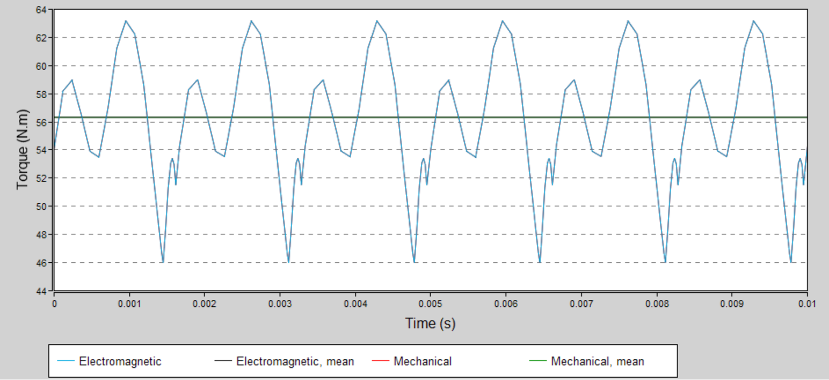


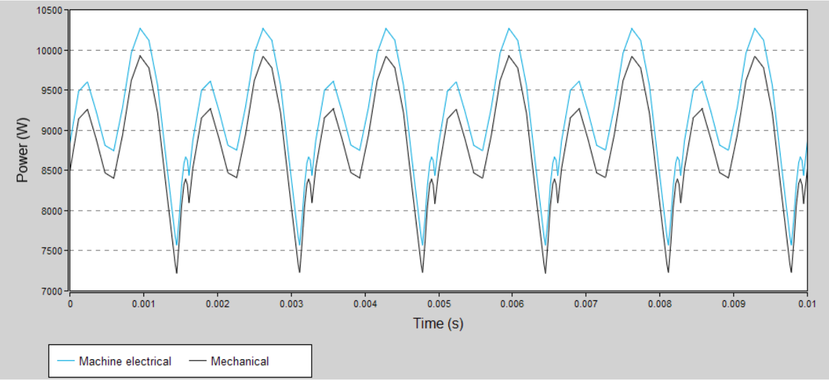


Working Point Analysis

With Square Wave currents







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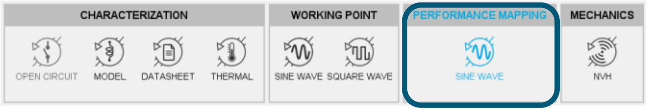
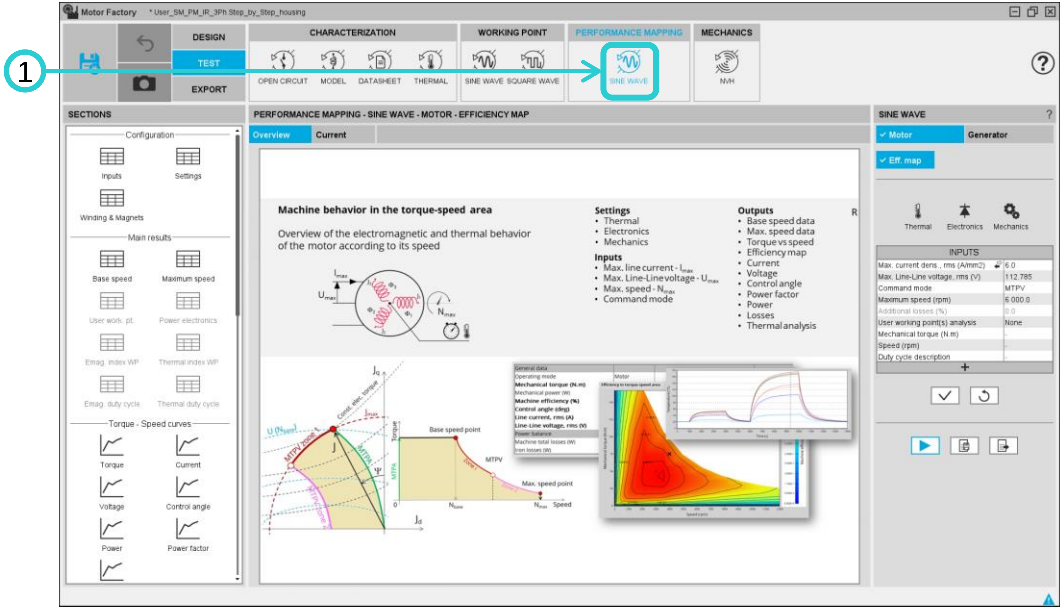
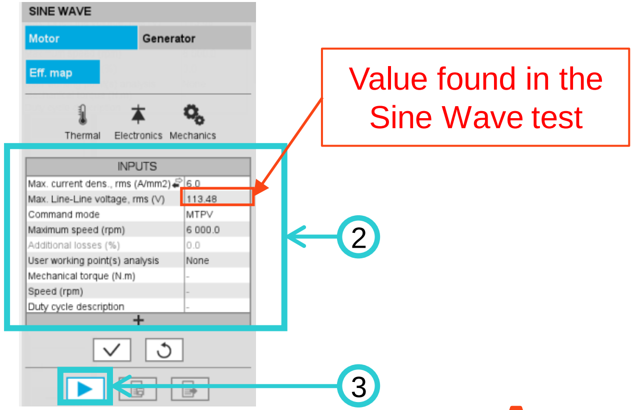
Efficiency Maps Computation



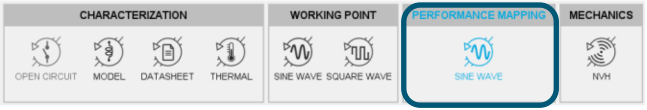
- Efficiency maps give an estimate of machine behavior at different speed/torque operating points. The map envelope represents the domain in which the machine operates. The point where one can have maximum torque and speed for a given command is called "Base Point".
- It is possible to define in this test the main characteristics of the motor, e.g., the selected command.

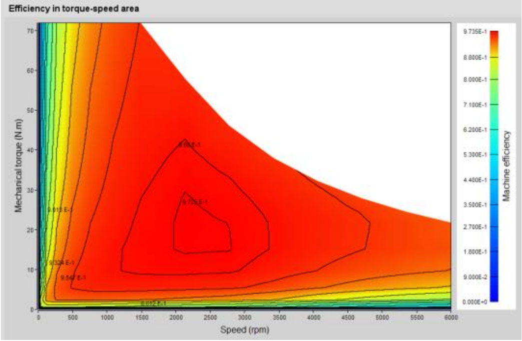


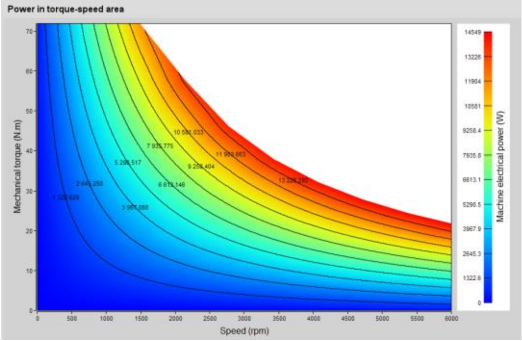
Step	Action
1	Choose performance mapping test
2	Fill in parameters
3	Launch computation

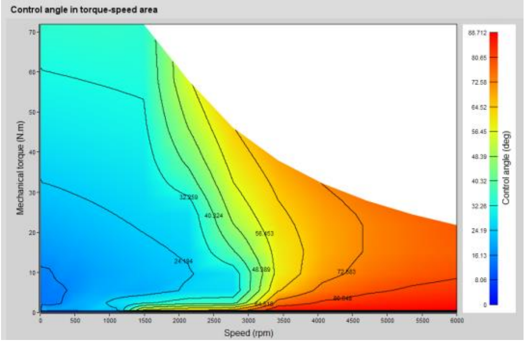


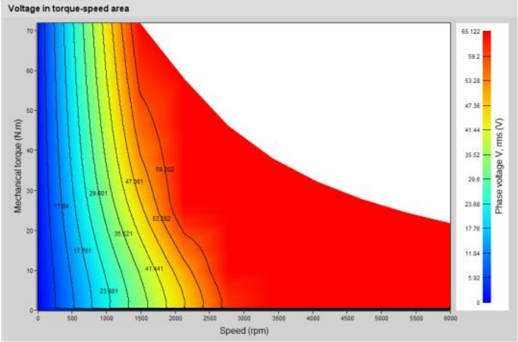
Efficiency Maps Computation

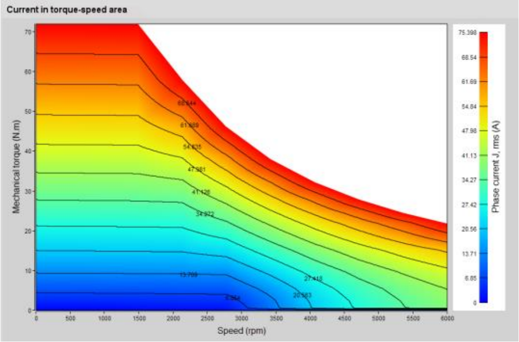


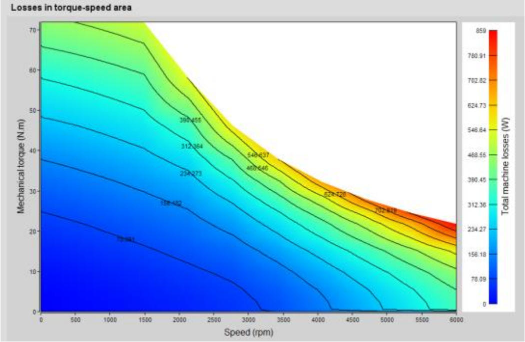






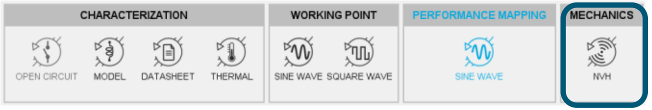




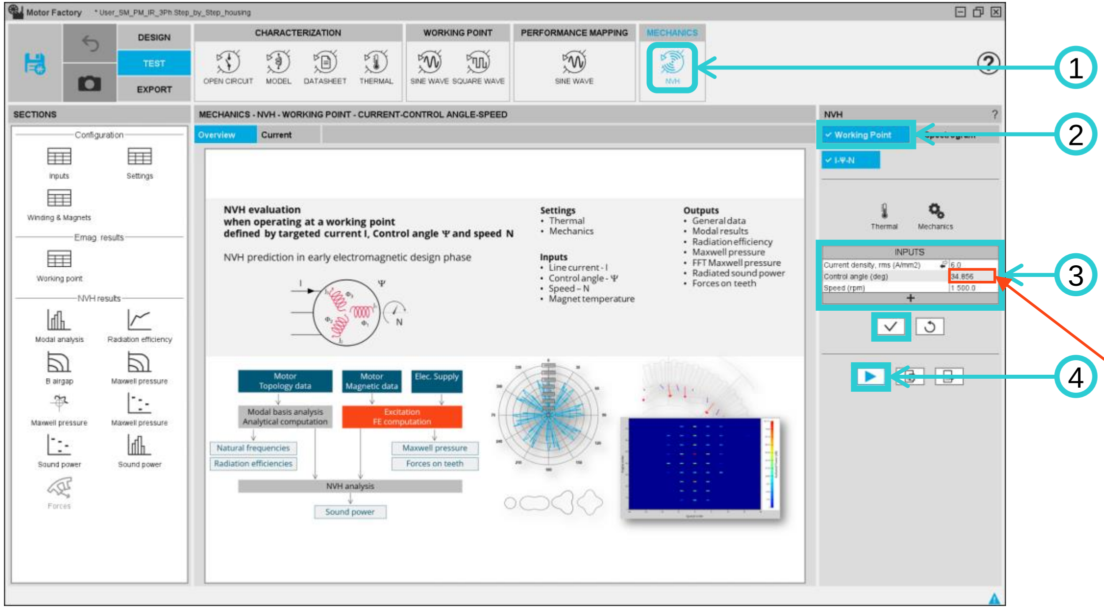


NVH Analysis

Working point NVH analysis



- Analysis of the electromagnetic forces in the air gap obtained from the magnetic flux density components
- Sound pressure level?

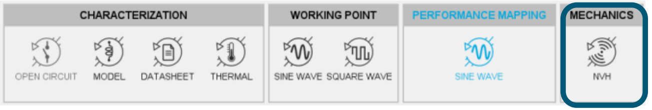


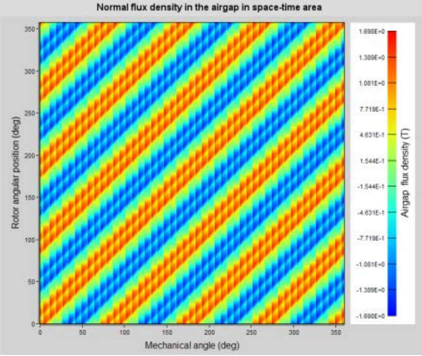
Step	Action
1	Choose NVH test
2	Choose working point test
3	Fill in the parameters
4	Launch computation

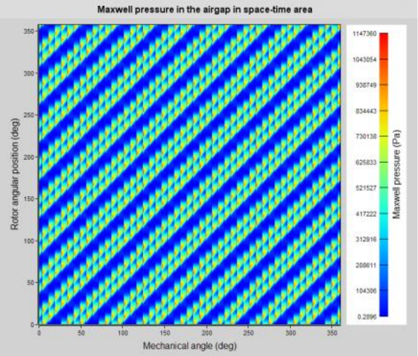
Value found in Datasheet test

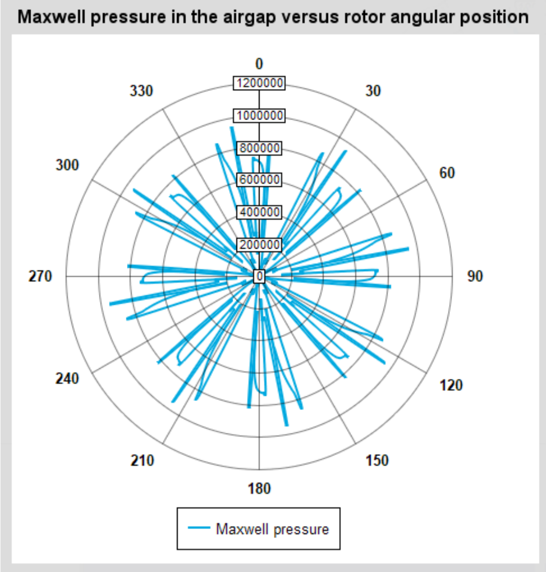
NVH Analysis

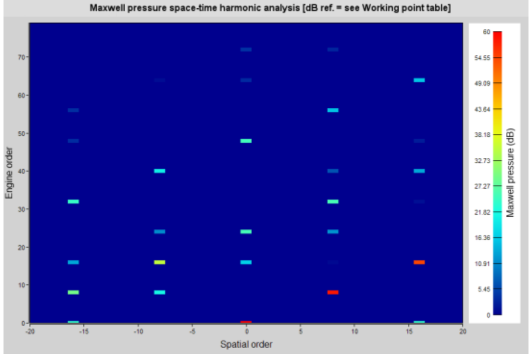
Working point NVH analysis results

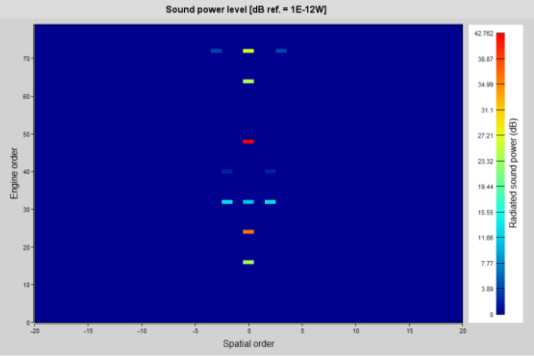












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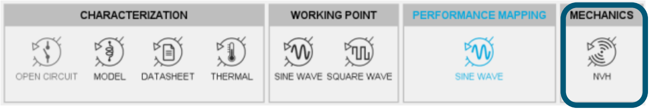
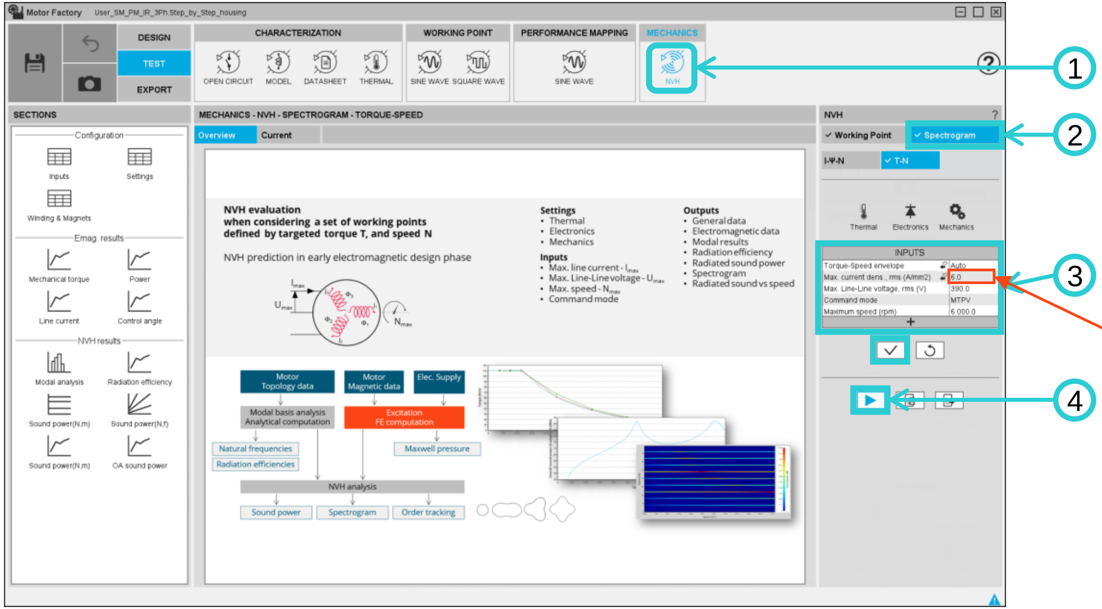
NVH Analysis

Spectrogram test





Step	Action
1	Choose NVH test
2	Choose Spectrogram test
3	Fill in the parameters
4	Launch computation

Value found in Datasheet test

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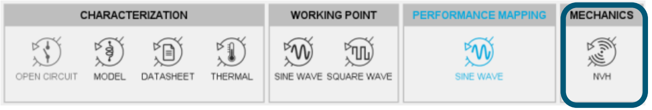
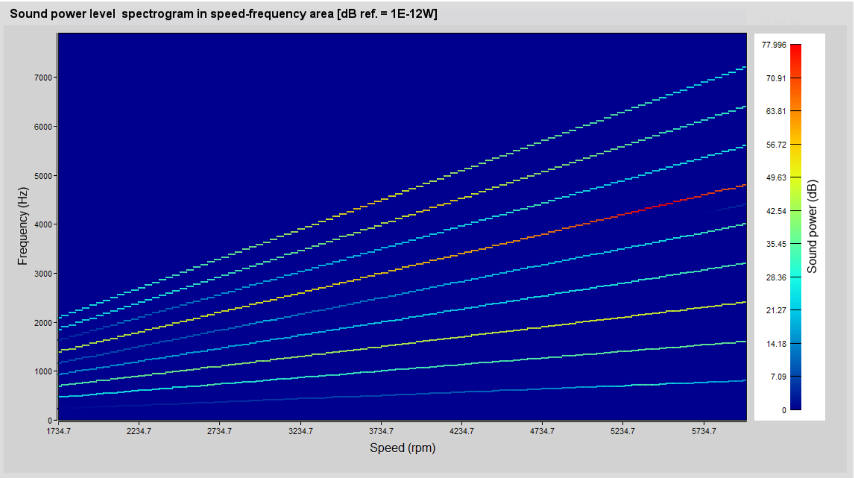
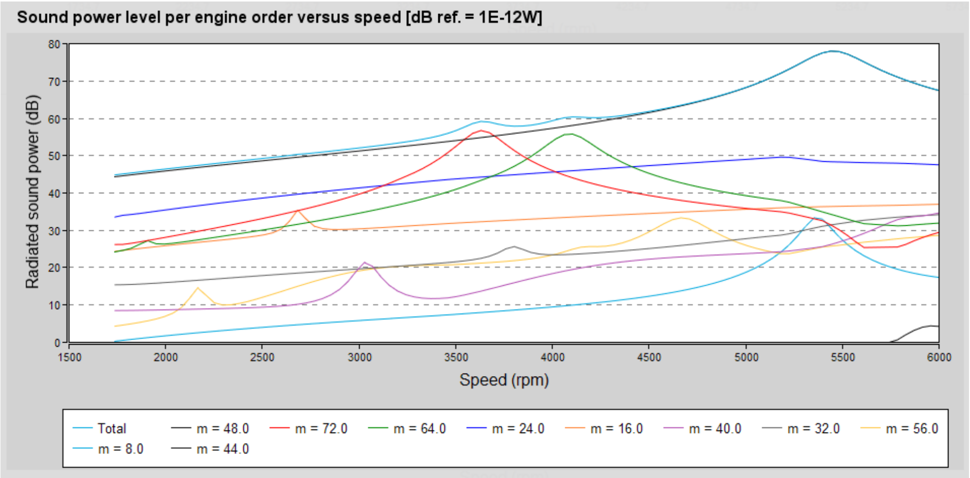
NVH Analysis

Spectrogram test



These graphics give an idea of the acoustic behaviour of our motor when making it do a speed ramp





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FLUXMOTOR EXPORT TO FLUX

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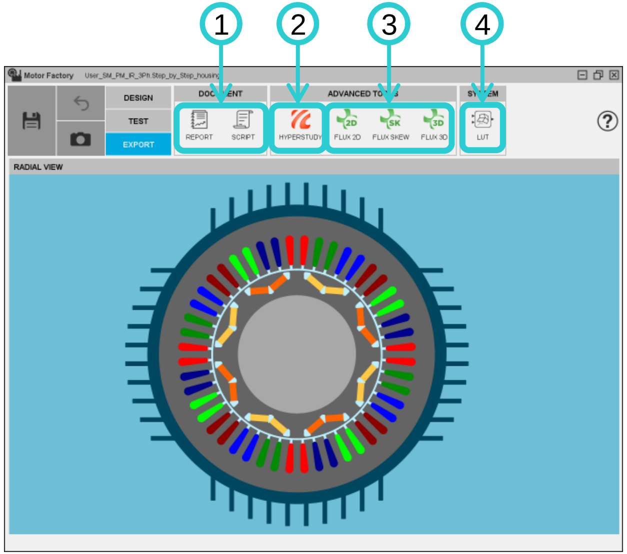
Export of the Project

Export Options

- The project defined in FluxMotor can be exported to Flux in order to carry out additional studies.
- This export is done by creating a Python code to be read in Flux in order to regenerate the geometry and physics of the project. The python code can be run within FluxMotor or be called in Flux to generate the Flux project.
- There are different type of exports :

1. Export to a document :
    - Report : Create a PDF or HTML file showing all the work achieved to design and test the machine.
    - “Script” : Build and export a python script file, in which all the needed command lines are written to rebuild the considered motor. This script can be used in Script Factory to automate some study.
2. HyperStudy : build a connector, allowing HyperStudy to drive FluxMotor for performing motor optimizations.
3. Export to Flux : Create a Python script that recreates the geometry and physics associated to a test in Flux.
4. Export machine maps, curves and constants (like LUT) in FMU and MAT format files to do a driving system analysis in Activate, PSIM, …



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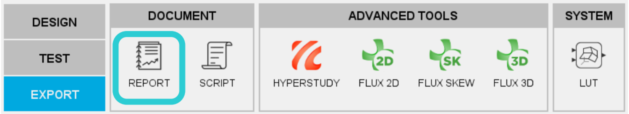
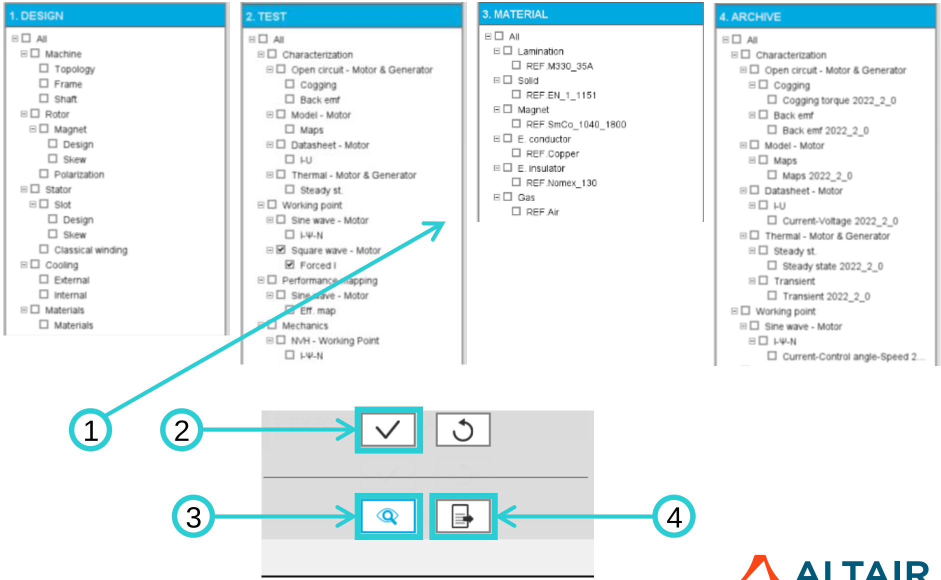


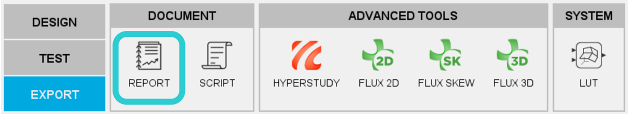
Export of the Project

Creation of a Report

- The aim of this export is to build and quickly export a report showing all the work achieved to design and test the machine.
- As a result, the report can be exported in a pdf or html file format. It can also be attached to the motor in the "Motor Catalog" or simply displayed in the report area.
- Various data can be shown in the report (Design, Test, Material and Archive).
- Each of this areas will represent a section of the report.

Step	Action
1	Select the sections you want to appear in the report
2	Validate the selection
3	See a preview of the report in FluxMotor interface
4	Export the report

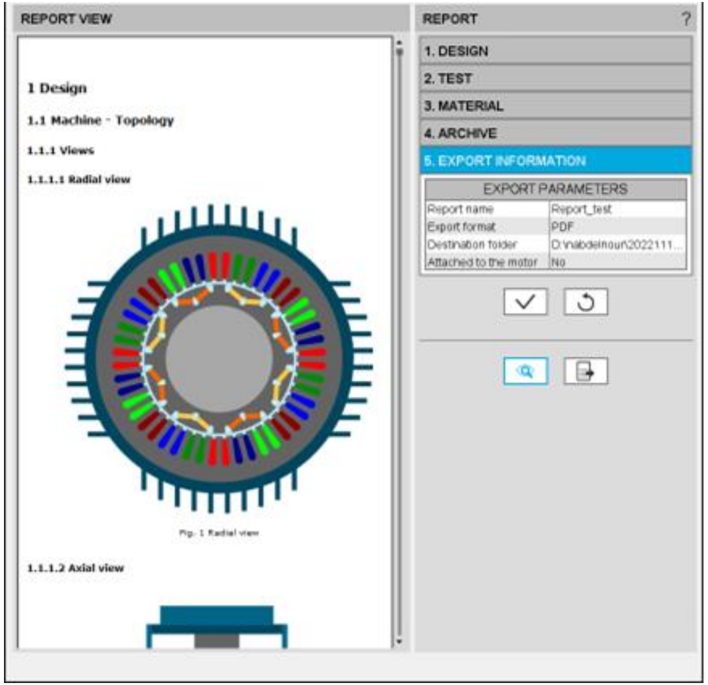




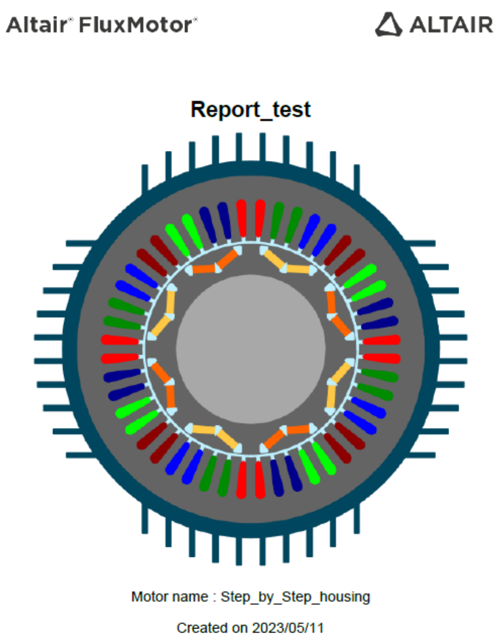
Export of the Project

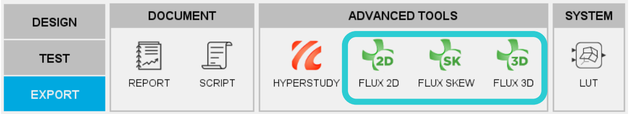
Visualization of a report

Report Preview



PDF Report

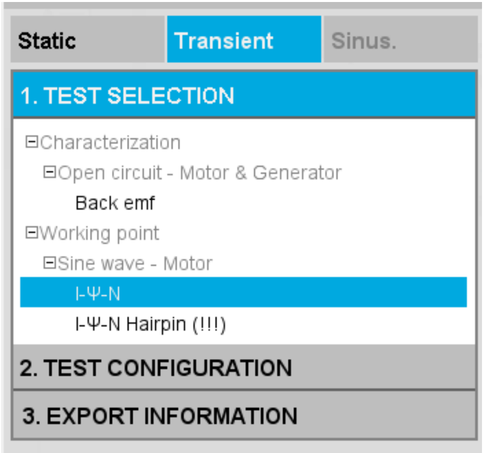




Export of the Project and Import in Flux

Geometry, physics and mesh defined in FluxMotor

- The project defined in FluxMotor can be exported to Flux in order to carry out additional studies.
- This export is done by creating a Python code to be read in Flux in order to regenerate the geometry and physics of the project. The python code can be run within FluxMotor or be called in Flux to generate the Flux project.
- In the current version, models can be exported for static application or transient application in Flux environments :



Application	Environment	Model family	Package	Convention	Model / Test
STATIC	2D	Without solving scenario	Current source	Motor & Generator	Basic model
	3D / Skew	Without solving scenario	Current source	Motor & Generator	Basic model
TRANSIENT	2D	Characterization	Open circuit	Motor & Generator	Back-EMF
		Working point	Sine wave	Motor	I-Ψ-N
		Working point	Sine wave	Motor	I-Ψ-N (Hairpin)
	Skew	Characterization	Open circuit	Motor & Generator	Back-EMF
		Working point	Sine wave	Motor	I-Ψ-N

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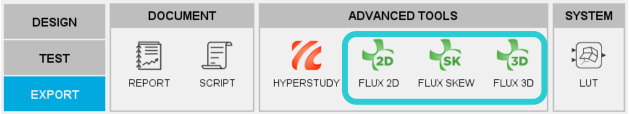
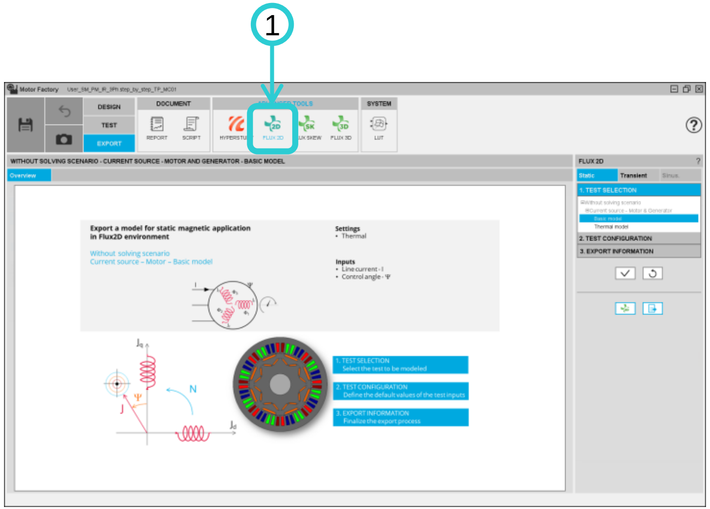


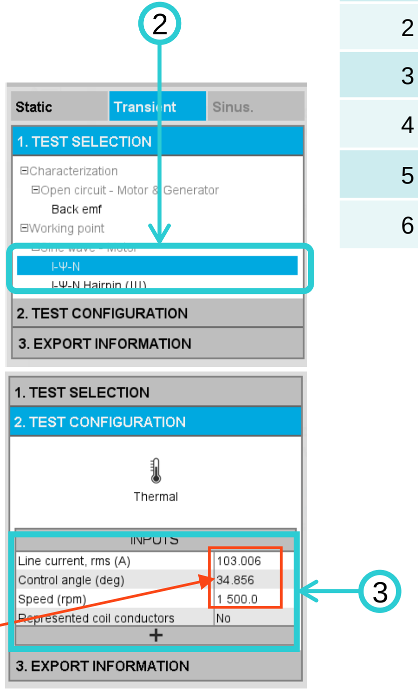
Export of the Project and Import in Flux

Geometry, physics and mesh defined in FluxMotor

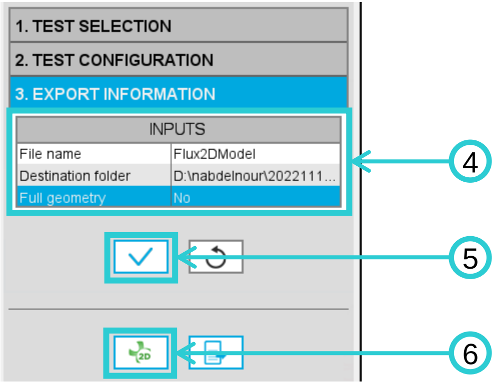
Here are quicksteps to create a transient magnetic model in Flux 2D with FluxMotor.

Step	Action
1	Enter Flux2D Export area
2	Select the Transient I-Ψ-N test
3	Fill in the test configuration inputs
4	
5	Validate the configuration inputs
6	





Values found in working point test



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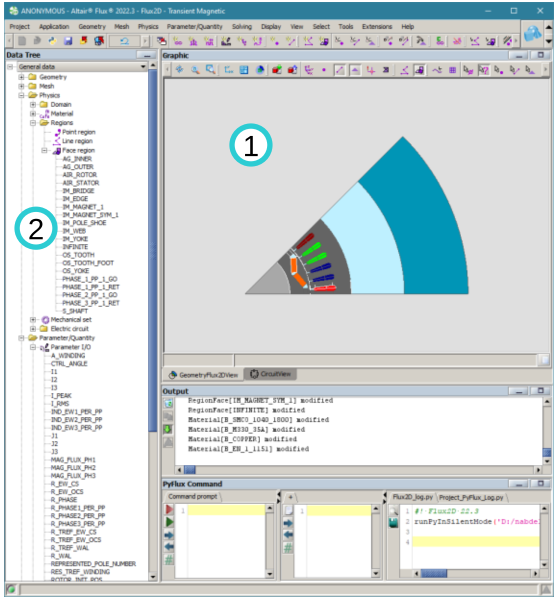
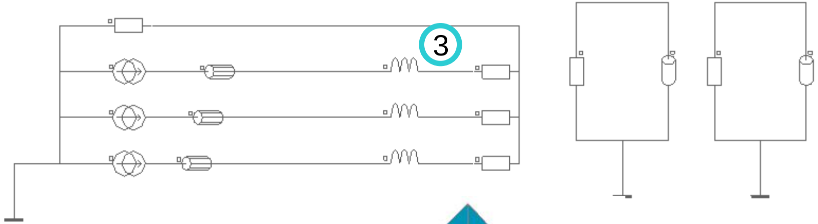
Export of the Project and Import in Flux

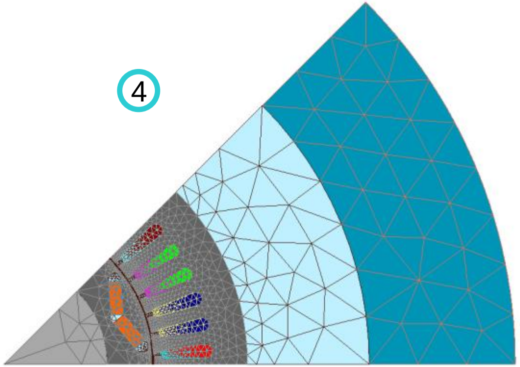
Transient model in Flux2D

The python script is run automatically in Flux after clicking the export button and a Flux window is opened where the geometry and physics of the project is regenerated. Regions, parameters (2), electric circuit (3) and motor mesh (4) are defined in the script and can be checked in the project.

This project can be used to run additional analyses on it.







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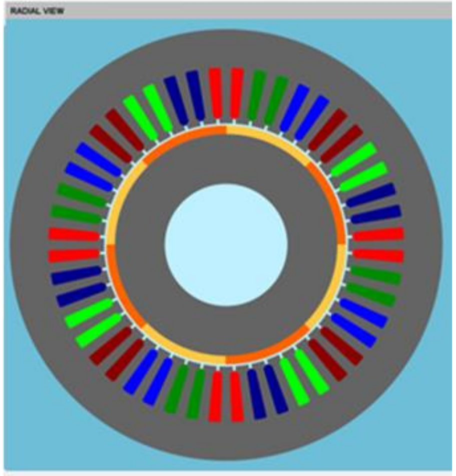
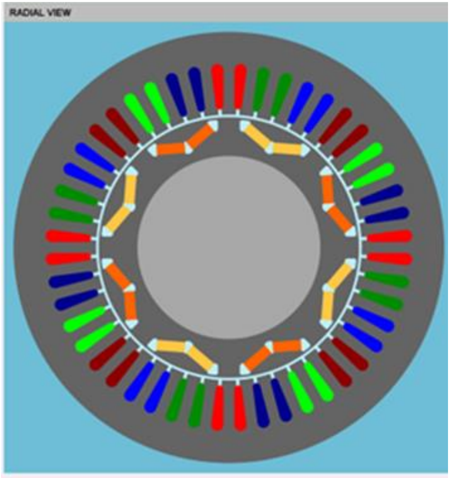
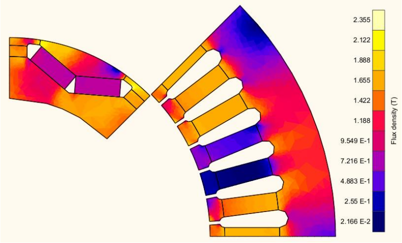
CONCLUSIONS

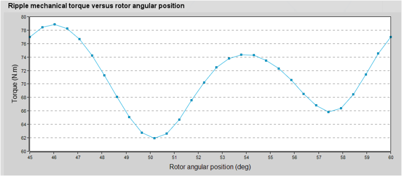
Conclusions

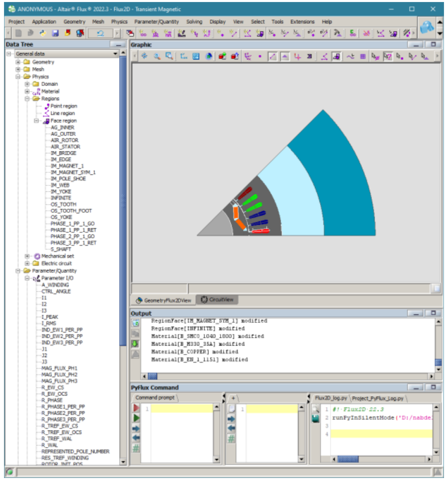
- This tutorial gives an overview of the basic workflow in FluxMotor. User can see the steps that allows him to :
  - *Create a geometry in the Design area of Motor Factory*
  - *Validate your topology by running tests and analysis in the Test area of Motor Factory*
  - *Export your FluxMotor project to Flux*











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THANK YOU

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