Altair® FluxMotor® 2026

Synchronous Machines with wound field – Inner salient pole - Inner rotor

Motor Factory - Test - Characterization

General user information

Altairhyperworks.com

Contents

1 CHARACTERIZATION – OPEN CIRCUIT – GENERATOR – NO LOAD

1.1 Overview

1.1.1 Positioning and objective

The aim of the test “**Characterization - Open circuit – Generator – No Load**” is to characterize the behavior of the machine when running in a no–load state.
The analysis of the machine’s no-load characteristics is a first step to evaluate the relevance of the machine design regarding not only parameters such as: topology, winding architecture, composition of coils and choice of materials, but also the impact of the applied field current value in the magnetic saturation of the machine.

Warning! When a delta winding connection is considered, the computation doesn’t consider circulation currents. That can lead to a different result than what expected in transient computation.
In such case, it is recommended to perform a transient computation in Flux® environment. The application “Export to Flux” allows exporting the model with the corresponding scenario ready to be solved.

The following table helps to classify the test “Open circuit – No Load”.

Family	Characterization
Package	Open circuit
Convention	Generator
Test	No Load

Positioning of the test “Characterization - Open circuit –Generator – No Load”

1.2 Main principles of computation

1.2.1 Back – emf computation

To get the Back-EMF versus Field current, successive Back-EMF tests must be performed with the corresponding field current values. For each field current value, the flux through each phase of the machine is computed for each rotor position over one half of electrical period. Inside FluxMotor®, this computation is carried out using Magnetostatic application of Flux® (Finite Element software). The computation is done by considering multiple positions of the rotor.

If a target point has been selected, a frequency analysis (Fast Fourier Transform F.F.T.) is then performed to extract the main harmonics of the signals.

$$E = \frac{d\Phi}{dt} = \frac{d\Phi}{d\theta} \times \frac{d\theta}{dt} = \frac{d\Phi}{d\theta} \times \Omega$$

Where Φ is the flux linkage and Ω is angular speed in rad/s.

If a target point has been selected, the line-line voltages are deduced from the three phase voltages.

1.2.2 Flux density in airgap

During the computation, a sensor put inside the airgap allows computing the flux density in the airgap versus rotor angular position.
It is located close to the stator bore diameter (at third quarter-length of airgap - stator side) in front of a stator tooth and remains motionless.

Like for the flux linkage, a Fast Fourier Transform is performed, and the main harmonics are extracted for flux density in airgap also.
The corresponding graphs and table are displayed.

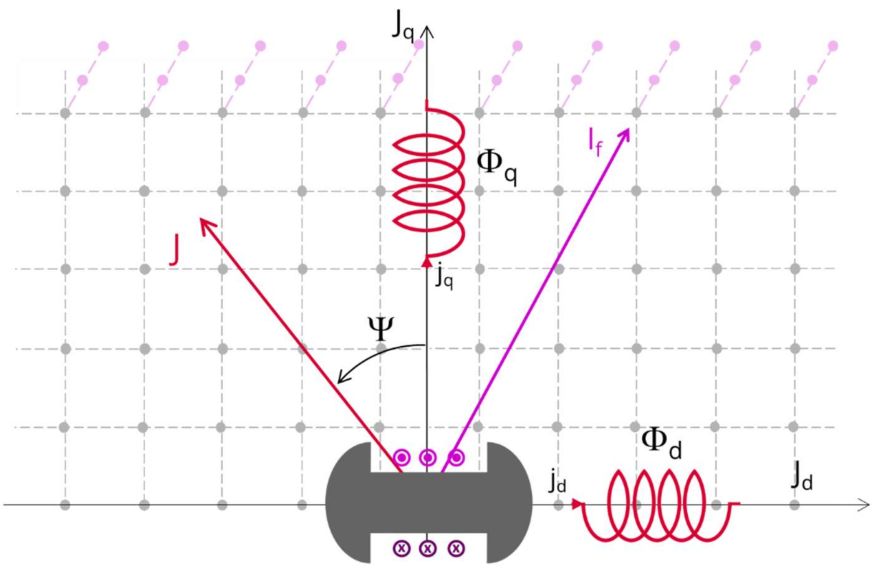
2 CHARACTERIZATION – MODEL – MOTOR – MAPS

2.1 Positioning and objective

The aim of the test “Characterization - Model - Motor - Maps” is to give maps along the three dimensions, If-J_d-J_q, for characterizing the 3-Phase synchronous machines with wound field.

These maps allow for predicting the behavior of the electrical rotating machine at a system level.

In this test, engineers will find a system integrator and / or control-command tool adapted to their needs and able to provide accurate maps ready to be used in system simulation software like Activate.



“Characterization - Model - Motor - Maps” illustration. Example for a second quadrant calculus.

The performance of the machine in steady state can be deduced from the results obtained in this test in association with the drive and control mode to be considered.

The following table helps to classify the test:

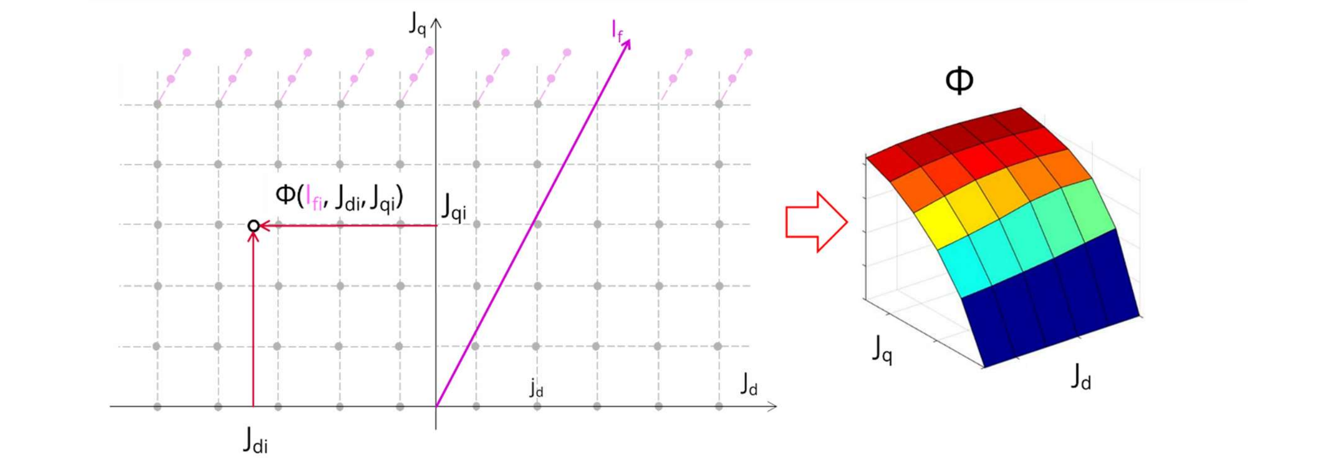
Family	Characterization
Package	Model
Convention	Motor
Test	Maps

Positioning of the test “Characterization - Model - Motor - Maps”

2.2 Main principles of computation

2.2.1 Flux linkage

One of the goals is to compute the D-axis and Q-axis flux linkage in the J_d, J_q planes at different levels of If between zero and the maximum value of If.
To do that, a grid of values (J_d, J_q) is considered for all levels of If.
For each node of this grid, the corresponding flux linkage through each phase is extracted (Φ_a, Φ_b, Φ_c) through the corresponding phases (a, b, c). This is done using Finite Element modeling (Flux® software – Magnetostatic application).
D-axis flux-linkage component - Φ_d and **Q-axis flux-linkage component -** Φ_q are deduced according to Park's transformation.



Computation on a grid in J_d, J_q plane at a level of I_f

Our modeling considers cross-saturation. However, winding harmonics and the variation of reluctance as a function of the angular position of the rotor are only considered if the "Rotor position dependency" input is "Yes".

Note: The impact on accuracy will be more important for machines with high level of saturation.

When the "Rotor position dependency" input is "No", i*ron loss computations are based on both Finite Element modeling and an analytical method where leakage flux between stator teeth is neglected. In case of high level of saturation, this hypothesis leads to more errors, particularly in the area where the field is weakening.*

When the "Rotor position dependency" input is "Yes", i*ron loss computations are based on Finite Element modeling with all considerations for flux leakage.*

Note: In the examples shown in the images, negative value of J_d and positive value of J_q are considered as the 2nd quadrant is chosen as example. However, the considered quadrants can be chosen through dedicated input (e.g., user can choose all quadrants or only the 2nd, the 2nd and 3rd ones, etc.), allowing the characterization of the machine behavior for other control conditions.

Note: In case the "Rotor position dependency" is set to "Yes", the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

2.2.2 Flux-linkage derivative respect to the rotor position

D-axis flux-linkage derivative with respect to the rotor position - $\Phi_d/d\theta_r$ and **Q-axis flux-linkage derivative with respect to the rotor position -** $\Phi_q/d\theta_r$ are computed from the flux linkage maps and using the following formula:

$$\frac{\Delta\Phi_d}{\Delta\theta_r}, \frac{\Delta\Phi_q}{\Delta\theta_r}$$

These maps are available only when the input Rotor position dependency is set to "Yes". The computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

Note 1: The rotor position derivative is always in radians per second to simplify the usage of this map while considering the Park's voltage equations.

2.2.3 Dynamic inductances

D-axis synchronous inductance - $L_{d\text{–dynamic}}$ and **Q-axis synchronous inductance - $L_{q\text{-dynamic}}$** are computed from the flux linkage maps and using the following formulas:

$$L_{d-\text{dynamic}} = \frac{\Delta\Phi_d}{\Delta J_d} \qquad L_{q-\text{dynamic}} = \frac{\Delta\Phi_q}{\Delta J_q}$$

Note 1: The end-winding leakage inductance L_{endw}, computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. The values of the dynamic inductances $L_{d\text{–dynamic}}$ and $L_{q\text{-dynamic}}$ consider the value of the end-winding inductance.

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

2.2.4 Dynamic cross inductances

D-axis synchronous cross inductance - $L_{dq\text{–dynamic}}$ and **Q-axis synchronous cross inductance - $L_{qd\text{-dynamic}}$** are computed from the flux linkage maps and using the following formula:

$$L_{dq-\text{dynamic}} = \frac{\Delta\Phi_d}{\Delta J_q} \qquad L_{qd-\text{dynamic}} = \frac{\Delta\Phi_q}{\Delta J_d}$$

Note 1: The end-winding leakage inductance L_{endw}, computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. However, the values of the dynamic cross inductances $L_{dq\text{–dynamic}}$ and $L_{qd\text{-dynamic}}$ are not impacted by the end-winding inductance value since they are obtained with the derivative of the D-axis and Q-axis flux-linkage with respect to current variation along the corresponding quadrature axis (Q-axis and D-axis, respectively).

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

2.2.5 Static inductances

D-axis synchronous inductance - $L_{d\text{-static}}$ and **Q-axis synchronous inductance - $L_{q\text{-static}}$** are computed from the flux linkage maps and using the following formula:

$$L_{d-\text{static}} = \frac{(\Phi_d - \phi_0)}{\sqrt{2} \times J_d} \qquad L_{q-\text{static}} = \frac{\Phi_q}{\sqrt{2} \times J_q}$$

ϕ_0 is the D-axis magnetic flux linkage component when J_d equals zero. This term corresponds to the magnetic flux linkage created by the field current If added to the flux created by the cross effect of J_q along the q-axis. Its value is a function of J_q and If.

Note 1: The end-winding leakage inductance L_{endw}, computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. The values of the static inductances $L_{d\text{–static}}$ and $L_{q\text{–static}}$ consider the value of the end-winding inductance.

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

2.2.6 Saliency

The saliency in the J_d-J_q area is computed and displayed as a map in J_d- J_q plane for all levels of If. This value corresponds to the ratio between q-axis and d-axis static inductances.

$$\text{Saliency} = \frac{L_{q-\text{static}}}{L_{d-\text{static}}}$$

Note: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

2.2.7 Electromagnetic torque

The **Electromagnetic torque T_{em}** is computed in different ways as a function of the input Rotor position dependency value.

2.2.7.1 Rotor position dependency set to "No"

The flux linkage maps, and the following formula are used:

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

Where m is the number of phases (3) and p is the number of pole pairs. J_d and J_q are the d and q axis peak currents.

2.2.7.2 Rotor position dependency set to "Yes"

The **Electromagnetic torque T_{em}** is computed thanks to finite element computation and the virtual work method to get the best evaluation of the ripple torque.

Note: In case the Rotor position dependency is set to "Yes", **Electromagnetic torque T_{em}** average value computed with the Park's equation or with virtual works is equal.

2.2.8 Iron loss computation

The **iron losses** are computed in a different way as a function of the value of the "Rotor position dependency" input.

2.2.8.1 Rotor position dependency set to "No"

A dedicated process has been developed to compute the **stator iron losses** (rotor iron losses are not computed).
Stator iron losses are computed only for the stator magnetic circuit built with lamination material (computation is not applicable for solid materials).

Our method of computation doesn't allow for computing iron losses on the rotor side. However, iron loss level is generally not very important on the rotor side in comparison with iron losses on the stator side.

For each node of the grid, in the three dimensions J_d-J_q-If defined and illustrated above, magnetic flux densities in stator teeth are obtained from a dedicated semi-numerical method based on the integration of the flux density in the airgap.

For each considered region (foot teeth, teeth, and yoke), we get the magnetic flux density as a function of the angular position. Then, the derivative of each magnetic flux density is computed as a function of the angular position.

At last, for each considered speed, a mathematical transformation is applied to get the derivative of magnetic flux density as a function of time.

$$\frac{dB}{dt}(t) = \frac{dB}{d\theta}(\theta) \times \frac{d\theta}{dt}$$

Total iron losses are computed considering the magnetic circuit volume, the density of materials used, and the stacking coefficient considered for the stator lamination.

2.2.8.2 Rotor position dependency set to "Yes"

The **iron losses, stator, and rotor** are computed thanks to the magnetostatic application of Flux (Finite Element modeling - MS FE) based on the magnetic flux derivative obtained over the finite element meshing.

The accuracy obtained is the same as the one with a magnetic transient finite element computation (MT FE) and for a given scenario, the MS FE computation time is approximately reduced by a factor 2 times lower than MT FE.

2.2.8.3 Model used to compute iron losses.

The model used to compute iron losses (W_{iron}) is:

$$W_{iron} = \left[\left(K_h \cdot \left(\frac{B_{max}}{K_f}\right)^{\alpha_h} \cdot f^{\beta h}\right) + \left(K_c \cdot \frac{1}{T_{elec}} \cdot \int_0^{Telec} \left[\frac{\left(\frac{dB}{dt}\right)}{K_f}\right]^{\alpha_c} dt\right) + \left(K_e \cdot \frac{1}{T_{elec}} \int_0^{Telec} \left[\frac{\left(\frac{dB}{dt}\right)}{K_f}\right]^{\alpha_e} dt\right)\right] . V_{iron} . K_f$$

With:
B_{max}: Peak value of the magnetic flux density (T)
f: Electrical frequency (Hz)
V_{iron}: Stator core lamination volume
K_f: Stacking factor.

The other parameters of this model are defined in the application dedicated to materials in FluxMotor®, i.e., “Materials”.

Note: In case the “Rotor position dependency” input is set to “No”, the impact on accuracy will be more important for a machine with a high level of saturation. In fact, the semi-numerical method used to compute the magnetic flux density of the stator teeth neglects flux leakage between teeth. This hypothesis will lead to more errors, particularly in areas where there is field weakening (generally applicable at high speeds).

2.2.9 Stator Joule losses

Joule losses in stator winding W_{Cus} are computed using the following formula:

$$W_{Cus} = m \times R_{ph} \times (J)^2$$

$$\underline{J} = J_d + jJ_q$$

$$|\underline{J}| = J = \sqrt{J_d^2 + J_q^2}$$

Where m is the number of phases (3 in the first version of FluxMotor®),
J is the rms value of the phase current (I is the line current. I = J with a Wye winding connection),
R_{ph} is the phase resistance computed according to the temperatures defined by user in the test settings.

Note 1: R_{ph} considers the resistance factor defined in the winding settings (DESIGN area of Motor Factory).

2.2.10 Rotor Joule losses

Joule losses in rotor winding W_{Cur} are computed using the following formula:

$$W_{Cur} = R_r \times I_f^2$$

If is the DC value of the field current,
R_r is the field resistance computed according to the temperatures defined by user in the test settings.

Note 1: R_r considers the resistance factor defined in the winding settings (DESIGN area of Motor Factory).

2.2.11 Mechanical losses

The mechanical losses are computed as a function of the speed.
For more details, please refer to the document: MotorFactory_SMPM_IOR_3PH_Test_Introduction – section “Mechanical loss model settings.”

2.2.12 Total losses

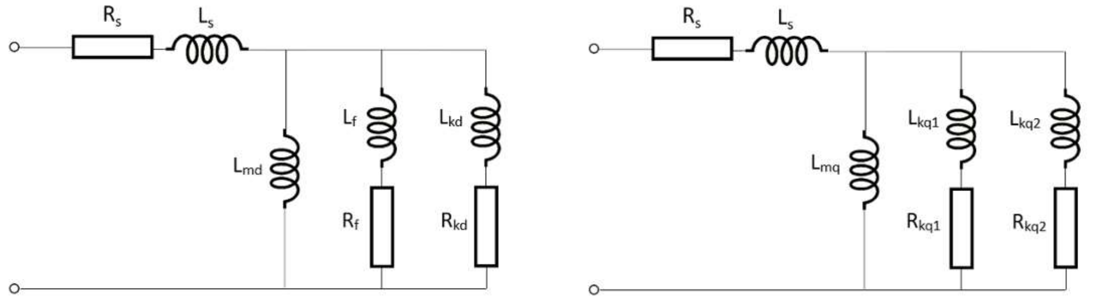
For each considered value of speed and currents J_d, J_q, If the amount of losses described above (Stator iron loss, Joule loss, and mechanical losses) are computed and displayed.
Note: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions If - J_d - J_q with an additional fourth axis corresponding to the rotor position θ_r.

3 CHARACTERIZATION – MODEL – MOTOR – SSFR

3.1 Overview

3.1.1 Positioning and objective

The aim of the test “**Characterization – Model – Motor – SSFR**” dedicated to the wound field synchronous machine is to characterize all the parameters of the D-axis and Q-axis equivalent schemes by performing a frequency analysis.



D-axis parameters of the equivalent circuit

Parameters					
Ls (H)	3.458 E-4	Lsw (H)	2.399 E-4	Lss (H)	1.059 E-4
Rs (Ω)	1.085 E-2	Lmd (H)	1.528 E-2		
Rf (Ω)	2.301 E-3	Lf (H)	1.823 E-3		
Rkd (Ω)	1.931 E-2	Lkd (H)	1.069 E-3		

Q-axis parameters of the equivalent circuit

Parameters					
Ls (H)	3.475 E-4	Lsw (H)	2.399 E-4	Lss (H)	1.076 E-4
Rs (Ω)	1.085 E-2	Lmq (H)	6.989 E-3		
Rkq1 (Ω)	1.762 E-2	Lkq1 (H)	1.029 E-3		
Rkq2 (Ω)	5.182 E-2	Lkq2 (H)	1.168 E-3		

Characterization – Model – Motor – SSFR” – Characterization of all the equivalent scheme parameters
D-axis and Q-axis equivalent scheme data – 2nd order is considered in the example above.

These results are based on the magnitude and the phase of the operational inductance transfer function which are computed with Finite Element software Flux® 2D.

The resulting reactances and time constants of the machines are also provided. Hence, such data can be used in system modeling tools like Altair® PSIM™ to evaluate the behavior of the machine with its drive and control system.

Reactances

Reactances					
Xd (Ω)	5.892	Xd' (Ω)	7.444 E-1	Xd" (Ω)	3.736 E-1
Xq (Ω)	2.766	Xq' (Ω)	4.692 E-1	Xq" (Ω)	3.223 E-1
Xs (Ω)	1.304 E-1	Xmd (Ω)	5.762	Xmq (Ω)	2.635
Reactances in per-unit system					
Reference impedance (Ω)	2.564				
Xd (%)	229.799	Xd' (%)	29.032	Xd" (%)	14.572
Xq (%)	107.865	Xq' (%)	18.298	Xq" (%)	12.571
Xs (%)	5.084	Xmd (%)	224.715	Xmq (%)	102.756

Time constants

Time constants					
Td' (s)	9.393 E-1	Td" (s)	7.012 E-2	Td0' (s)	7.435
Td0" (s)	1.397 E-1				
Tq' (s)	7.719 E-2	Tq" (s)	2.738 E-2	Tq0' (s)	4.551 E-1
Tq0" (s)	3.986 E-2				

Reactances and time constants of the machine are computed

The following table helps to classify the test "Characterization – Model – Motor – SSFR".

Family	Characterization
Package	Model
Convention	Motor
Test	SSFR

Positioning of the test "Characterization – Model – Motor – SSFR"

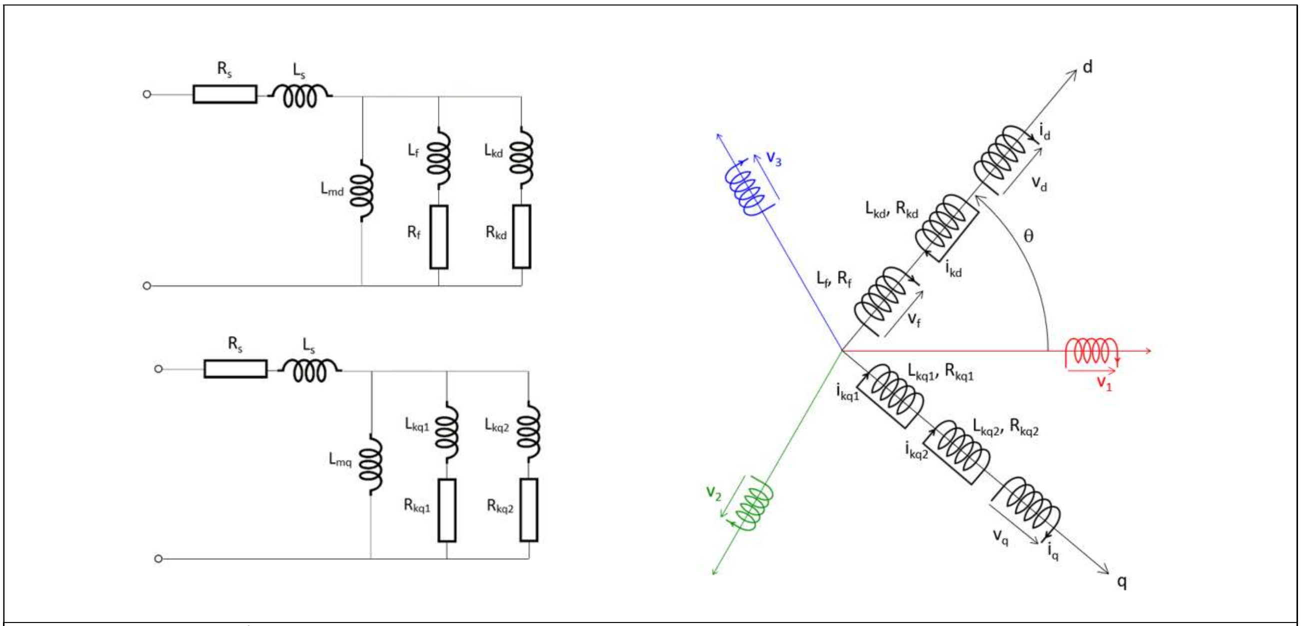
3.2 Main principles of computation

3.2.1 Introduction

As said previously, the aim of the test "Characterization – Model – Motor – SSFR" is to identify all the parameters of the electrical equivalent scheme of a 3-Phase wound field synchronous machine by considering either a first order or a second order for the D-axis and Q-axis operational inductance transfer function L(p).

3.2.2 Model representation

3.2.2.1 Second order D-Axis and Q-Axis model



2nd order equivalent scheme of the wound field synchronous machine with dampers

Notes:

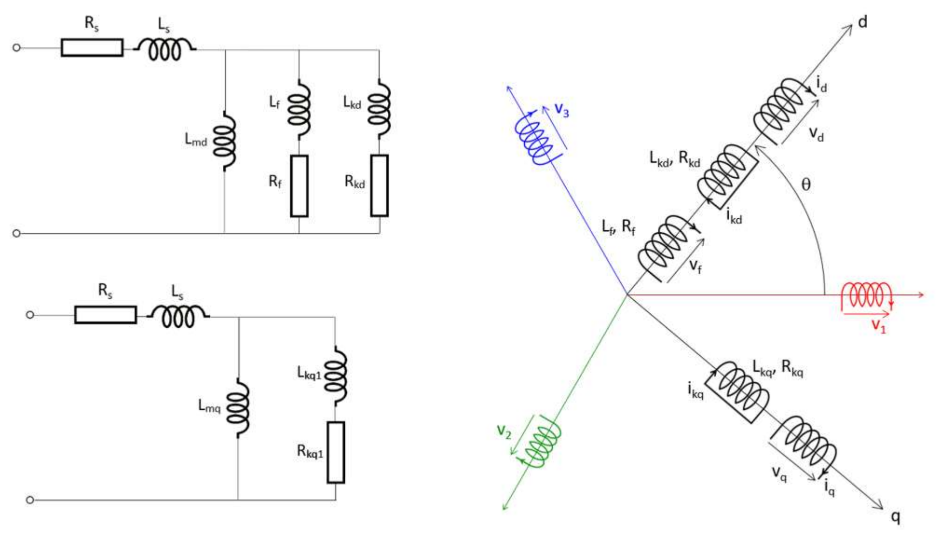
On the previous and following graphs, θ represents the relative position between the first stator winding phase and the d-axis of the machine model.
All the components displayed in the picture correspond to the equivalent scheme parameters. For more information, please refer to the user help guides.

Here is the list of the second order equivalent scheme parameters:

R_s: Stator phase resistance
L_s: Stator phase leakage inductance = (L_{sw} + L_{ss})
L_{sw}: Stator end winding leakage inductance (included in L_s)
L_{ss}: Stator straight part leakage inductance (included in L_s)
L_{md}: D-axis magnetizing inductance

R_f: Field resistance
L_f: Field inductance
R_{kd}: D-axis damper resistance
L_{kd}: D-axis damper inductance
L_{mq}: Q-axis magnetizing inductance
R_{kq1}: Q-axis damper resistance – 1st branch
L_{kq1}: Q-axis damper inductance – 1st branch
R_{kq2}: Q-axis damper resistance – 2nd branch
L_{kq2}: Q-axis damper inductance – 2nd branch

3.2.2.2 Second order D-Axis and first order Q-Axis model

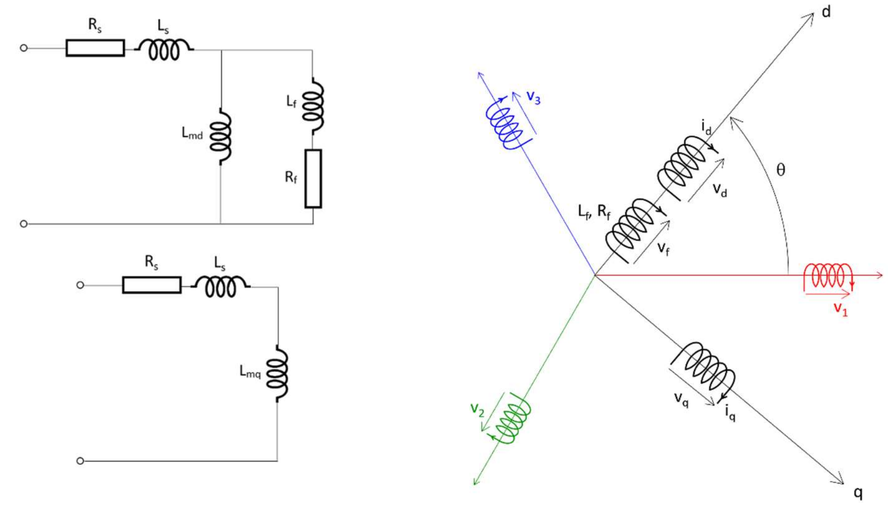


D-Axis 2nd order equivalent scheme and Q-Axis 1st order equivalent scheme
of the wound field synchronous machine with dampers

Here is the list of the first order equivalent scheme parameters:

R_s: Stator phase resistance
L_s: Stator phase leakage inductance = (L_{sw} + L_{ss})
L_{sw}: Stator end winding leakage inductance (included in L_s)
L_{ss}: Stator straight part leakage inductance (included in L_s)
L_{md}: D-axis magnetizing inductance
R_f: Field resistance
L_f: Field inductance
R_{kd}: D-axis damper resistance
L_{kd}: D-axis damper inductance
L_{mq}: Q-axis magnetizing inductance
R_{kq1}: Q-axis damper resistance – 1st branch
L_{kq1}: Q-axis damper inductance – 1st branch

3.2.2.3 First order D-Axis and zero order Q-Axis model



D-Axis 1st order equivalent scheme and Q-Axis Zero order equivalent scheme
of the wound field synchronous machine without dampers

Here is the list of the first order equivalent scheme parameters:

R_s: Stator phase resistance
L_s: Stator phase leakage inductance = (L_{sw} + L_{ss})
L_{sw}: Stator end winding leakage inductance (included in L_s)
L_{ss}: Stator straight part leakage inductance (included in L_s)
L_{md}: D-axis magnetizing inductance
R_f: Field resistance
L_f: Field inductance
L_{mq}: Q-axis magnetizing inductance

3.2.3 Test procedure

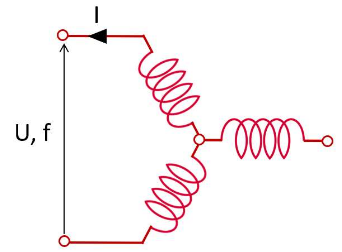
3.2.3.1 Short description

The rotor of the machine does not rotate. Two positions are considered for the rotor angular position, one to characterize the D-axis parameters and another one to characterize the Q-axis parameters. Hence, the following process is performed twice, once for each rotor angular position.

By considering a 3-Phase wound field synchronous machine, the magnitude and a phase angle of the machine's operational inductance L(p) are computed versus the frequency for the D-axis and the Q-axis.

The operational inductance L(p) is deduced from the impedance Z(p) as a magnitude and a phase angle, then formulated as a transfer function.
To perform these computations, a frequency analysis is carried out over a range of frequencies between 0.1 mHz and 1 kHz, considering 10 frequency values per decade. These computations are performed with Finite Element tool Flux® 2D – Steady state AC application.

As a result, the wound field synchronous machine is characterized on both D-axis and Q-axis by its frequency response, which is the magnitude and phase angle of the operational inductance transfer function versus the frequency.



A voltage U is applied between two phases

The operational inductance transfer function is deduced from the applied voltage and frequency as follows:

$$\frac{U}{I} = Z(p) = -2 \times [R_S + p \times L(p)]$$

Depending on the operational inductance transfer function order, the corresponding analytical formula of L(p) is represented as illustrated below:

$L(p) = A\frac{1 + Bp}{1 + Cp}$	$L(p) = A\frac{1 + Bp + Cp^2}{1 + Dp + Ep^2}$
1st order operational inductance transfer function	2nd order operational inductance transfer function

Then, an internal optimization process computes for each axis all the corresponding parameters (A, B, C, D, and E) to make both results from the analytical approach and Finite Element tool computation as close as possible.

For the Q-axis zero order operational inductance, the only parameter for the transfer function is A, and no optimization process is run, since it will be equal to the magnitude of the first point provided by the Finite Element tool computation with a zero degree of phase, i.e., a constant real value.

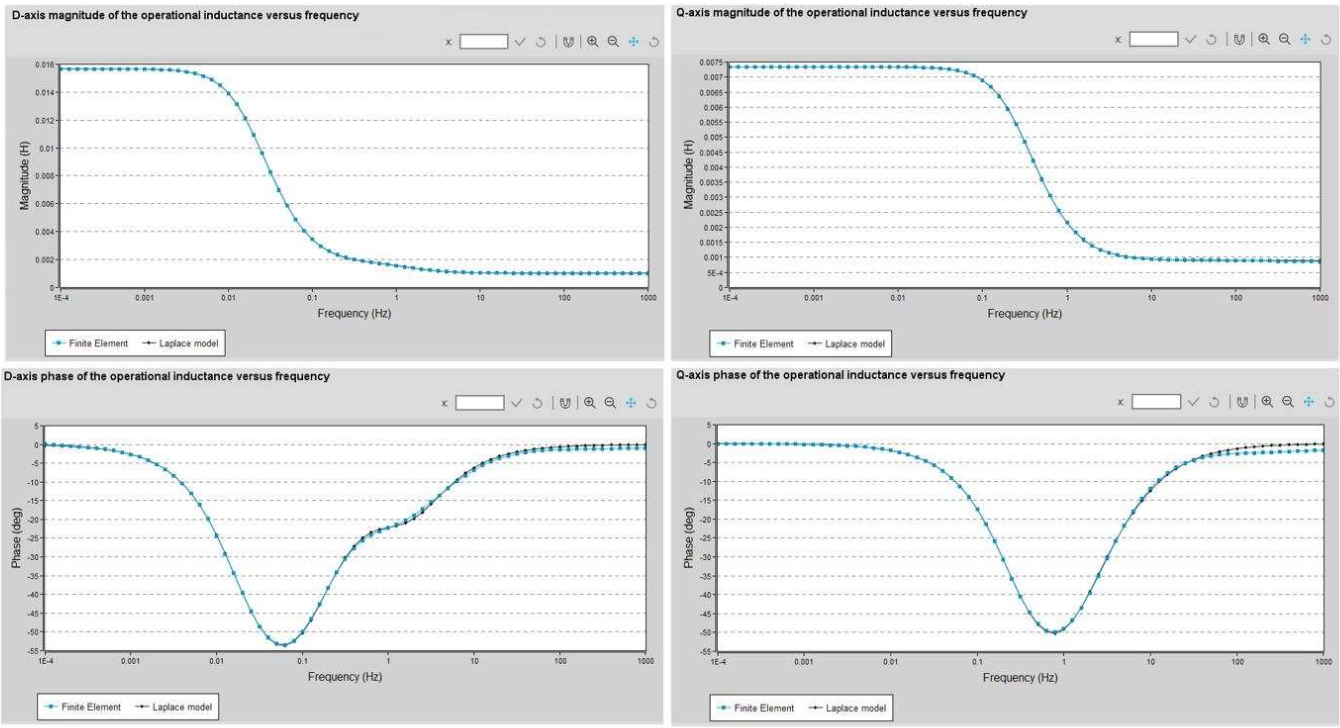
Theoretical analytical formulas allow deducing all the D-axis and Q-axis equivalent scheme parameters from operational inductance transfer function coefficients.

Here are results to illustrate this comparison in the test area.

Blue points (curves) correspond to Finite Element computation results.
Black points (curves) correspond to analytical computations based on equivalent operational inductance transfer function.

The aim of the internal optimization process is to make these two resulting curves as close as possible to each other by acting on the L(p) parameters.

Modeling of a wound field synchronous machine with dampers - using a second order operational inductance for both the D-axis and Q-axis.



Magnitude and a phase of the D-Axis and Q-Axis operational inductance L(p) vs frequency

For additional information regarding D-axis and Q-axis operational inductance model order selection, please refer to the Best Practices document: MotorFactory_Test_BestPractices.

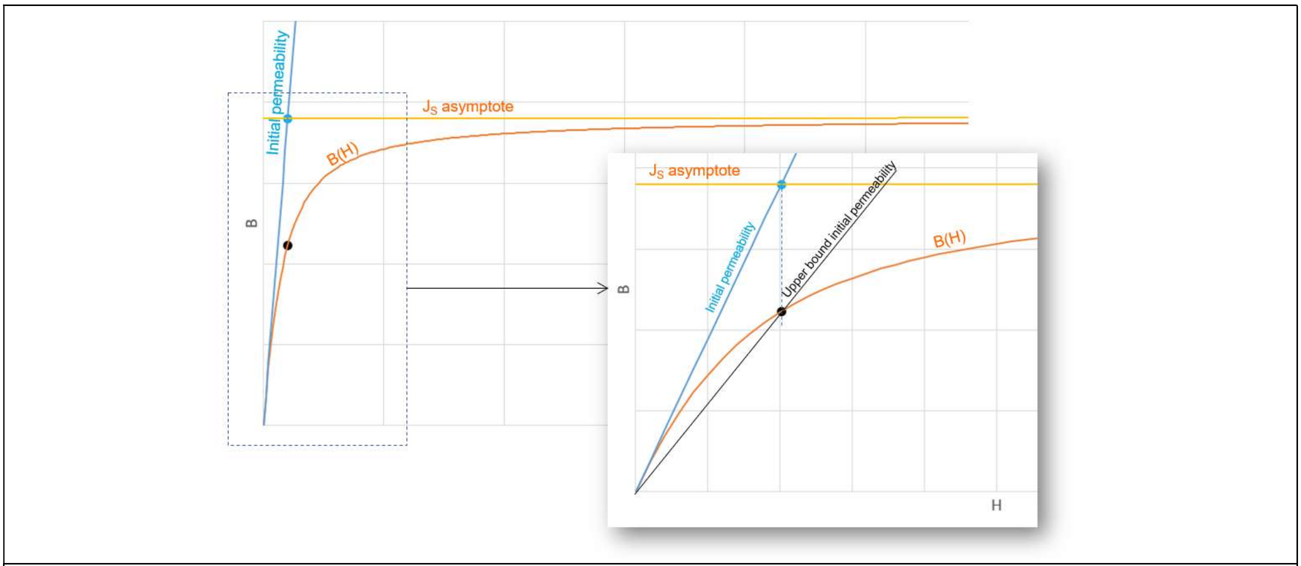
3.2.3.2 Additional information

1) Materials magnetic properties

To meet the requirements of the test assumptions, the computations with Finite Elements are operated by considering linear ferromagnetic materials.

The constant value of each material magnetic permeability is computed by considering a mean value in the very first part of the considered B(H) curve.

From a practical point of view, the constant magnetic permeability used in the computation is the average value of initial and the upper bound permeability defined as below illustrated.



Definition of constant magnetic permeability used for computations with Finite Elements software

2) Stator phase leakage inductance computation

L_s is the stator phase leakage inductance.
L_{sw} is the stator end winding leakage inductance.
L_{ss} is the stator straight part leakage inductance (including slot leakage inductance)

L_{sw} corresponds to the total end winding inductance (including the two sides of the machine). It is computed in the winding area environment with analytical method of computation.

The stator straight part leakage (L_{ss}) is computed from the magnetic energy stored in the slots along the half part of the airgap close to the stator bore diameter.
The total value of the stator phase leakage inductance (L_s) is computed as follows:

$$L_s = (L_{sw} + L_{ss})$$

The D-axis and Q-axis magnetization inductances are deduced using the following formulae:

$$L_{md} = L_d - L_s$$
$$L_{mq} = L_q - L_s$$

Where L_d is the D-axis phase winding inductance, which corresponds to the A parameter of the D-axis operational inductance, which corresponds to the inductance at low frequency.
L_q is the Q-axis phase winding inductance, which corresponds to the A parameter of the Q-axis operational inductance, which corresponds to the inductance at low frequency.

$L(p) = A\frac{1 + Bp}{1 + Cp}$	$L(p) = A\frac{1 + Bp + Cp^2}{1 + Dp + Ep^2}$
1st order operational inductance transfer function	2nd order operational inductance transfer function