Altair® FluxMotor® 2026

Synchronous machines – Permanent magnets - Inner & Outer rotor

Motor Factory – Test - Working point

General user information

Altairhyperworks.com

Contents

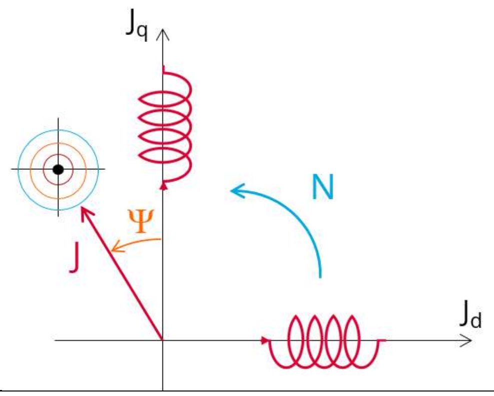
1 WORKING POINT – SINE WAVE – MOTOR – I, Ψ, N

1.1 Overview

1.1.1 Positioning and objective

The aim of the test "**Working point – Sine wave – Motor – I, Ψ, N"** is to characterize the behavior of the machine when operating at the targeted input values I, Ψ, N (Magnitude of current, Control angle, Speed).
These three inputs are enough to impose a precise working point.

For instance, a working point can be chosen on the efficiency map, by identifying the current, the control angle and the speed with different curves or maps displayed in the "Performance mapping / Sine wave / Motor / Efficiency map" test. Then, the "Working point – Sine wave – Motor – I, Ψ, N" test allows to compute the performance for this working point.



"Working point – Sine wave – Motor – I, Ψ, N" illustration

The results of this test give an overview of the electromagnetic analysis of the machine considering its topology.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed. The motor convention is used to build the model.
The magnetic flux density is also computed in every region of the machine's magnetic circuit to evaluate the design.

Two computation modes are available:
- "Fast computation mode" is perfectly suited for the pre-design step (Hybrid model based on Magneto-Static Finite Element computations and Park transformation theory)
- "Accurate computation mode" is perfectly suited for the final design step (Pure Finite Element modeling based on transient computations)

It also gives the capability to make comparisons between the results obtained from the measurements and those obtained with Altair® FluxMotor®.

When both the following conditions are met, this test allows electromagnetic computations with coupled thermal analysis.

- The type of machine is Synchronous Machine with Permanent Magnets with Inner rotor
- Iterative thermal solving can be selected.

The following table helps to classify the test "Working point – Sine wave – Motor – I, Ψ, N".

Family	Working point
Package	Sine wave
Convention	Motor
Test	I, Ψ, N

Positioning of the test "Working point – Sine wave – Motor – I, Ψ, N"

1.2 Main principles of computation

1.2.1 Introduction

The aim of this test in motor convention is to give a good overview of the electromagnetic potential of the machine by characterizing the working point according to the line current, control angle and speed set by the user.
In addition, ripple torque at the working point is also computed.

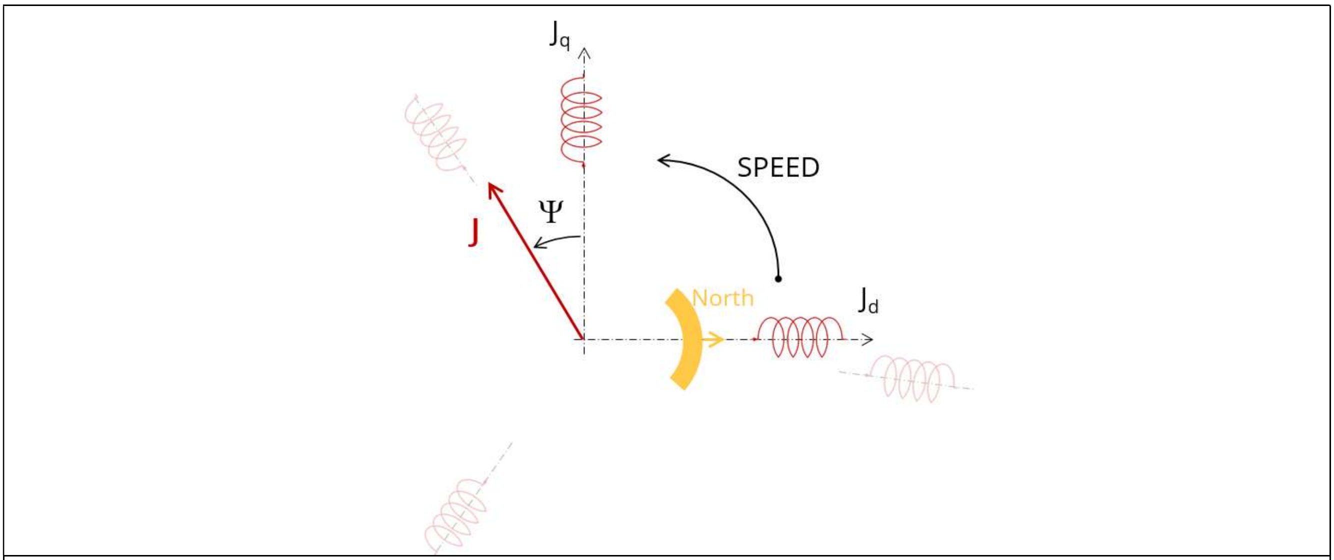
Two computation modes are available:

- “Fast computation mode” is perfectly suited for the pre-design step to explore the space of solutions quickly and easily (Hybrid model based on magnetostatic FE computations and Park transformation)
- “Accurate computation mode” is perfectly suited for the final design step because it allows getting more accurate results and to compute additional quantities like the AC losses in winding, rotor iron losses and Joule losses in magnets (Pure FE model based on transient computations)

1.2.2 Fast computation mode

1.2.2.1 Working point - Definition

To compute the working point, the principle consists of positioning the magnet axis towards the reference phase axis by considering the targeted control angle.
At the same time, the targeted line current and speed are imposed.
Then, the resulting behavior of the machine can be simulated, and all the main electromagnetic characteristics of the machine can be deduced by using Park’s transformation and associated electric equations.



Magnet axis and reference phase axis Positioning – Motor convention

1.2.2.2 Electromagnetic behavior – General information

The method used for computation of electromagnetic behavior depends on if rotor position dependency is set to “Yes” or “No”:

- “Yes” is selected: The analysis of the electromagnetic behavior is done over the number of computed electrical periods defined by users.
- “No” is selected: The analysis of the electromagnetic behavior is done through a dedicated static computation (1 rotor position to be considered) for the computed working point (with line current, control angle and speed obtained for the working point).

1.2.2.3 Flux in airgap

The flux in the airgap is always computed thanks to the dedicated static computation of the working point.

The airgap flux density is computed along a path in the airgap in Flux® software. The resulting signal is obtained for at least an electric period. The average and the peak value of the flux density are also computed. The harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic of the flux density.

1.2.2.4 Flux density in iron

Mean and maximum values of flux density of each iron region are computed thanks to sensors in Flux® software.

1.2.2.5 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed thanks to sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

1.2.2.6 Ripple torque

A specific computation is performed to precisely determine the rate of ripple torque.
Considering J_d and J_q at the base speed point, a computation is performed over one ripple torque period by using Finite Element modelling (Flux® software – Magnetostatic application).
Many computation points are considered over the ripple torque period (advanced user input: **No. comp. / ripple period**).
The following steps are performed to determinate the mechanical torque.

1) Original computation of the electromagnetic torque

The magnetic torque exerted on a non-deformable part of the domain is computed by the virtual work method. The torque in a direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in the regional volume

The electromagnetic ripple torque is computed over the ripple torque period with respect of the rotor angular position $T_{em,\theta}$. The mean value "$T_{em,\ mean}$" can also be computed.

2) Mechanical ripple torque based on Park's model

The mechanical ripple torque must be computed at the base speed.
First, we compute the electromagnetic torque "$T_{em,\ Park}$" with Park's model:

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

Then, the iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em,\ Park}$" to get the corresponding mean value of the mechanical torque "$T_{mech,\ Park}$".

3) Resulting mechanical torque versus rotor angular position

To compute the resulting mechanical ripple torque, the original electromagnetic torque computed previously is weighted by the ratio of the mean value of the mechanical torque based on Park's model ($T_{mech,\ Park}$) and of the mean value of the original electromagnetic ripple torque ($T_{em,\ mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,Park}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

Warning: When the ripple torque computation is not requested, the computation of the working point is performed by considering only one position within the electrical period. It means that all the data characterizing the behavior of the machine can change based on the selection of ripple torque (Yes/No).
Flux density in magnetic circuit and the magnet behavior will be more accurately computed when the computation of the ripple torque will be requested.

1.2.3 Accurate computation mode

1.2.3.1 Working point - Definition

Working point computation is based on a transient magnetic finite element simulation over a half, one or several electrical periods for a given set of inputs: control angle, line current and speed defined as for the Fast computation mode.
Thus, all the main electromagnetic characteristics of the machine can be deduced accurately.

1.2.3.2 Electromagnetic behavior – General information

All the main quantities are directly computed from the Flux® software in the framework of a transient magnetic finite element simulation.

1.2.3.3 Iron losses

Iron losses (stator and rotor) are computed, thanks to the “transient modified Bertotti model” in Flux® software.

1.2.3.4 Magnet losses

Magnet losses are computed thanks to the sensors defined for each corresponding region in Flux® software.

1.2.3.5 Stator Joule winding losses

The stator’s DC Joule losses are always computed.
However, if AC losses analysis is set to “FE-One phase” or “FE-all phase” stator AC Joule losses are computed in addition to stator’s DC Joule losses.

FE-One phase: AC losses are computed with only one phase modeled for solid conductors (wires) inside the slots. The two other ones are modeled with coil regions. Thus, AC losses in winding are computed with a lower computation time than if all the phases were modeled with solid conductors. However, this can have a little impact on the accuracy of results because we have supposed that the magnetic field is not impacted by the modeling assumption.

FE-All phase: AC losses are computed, with all phases modeled with solid conductors (wires) inside the slots. This computation method gives the best results in terms of accuracy, but with a higher computation time.

FE-Hybrid: AC losses in winding are computed without representing the wires (strands, solid conductors) inside the slots.
Since the location of each wire is accurately defined in the winding environment, sensors evaluate the evolution of the flux density close each wire. Then, a postprocessing based on analytical approaches computes the resulting current density inside the conductors and the corresponding Joule losses.
With the “FE-Hybrid” option the accuracy of results is good especially when the wire size is small (let’s say wire diameter lower than 2.5 mm). However, this can have a little impact on the accuracy of results because we have supposed that the magnetic field is not impacted by the modeling assumption.

In FluxMotor®, stator AC Joule losses corresponds to the additional losses induced by fields and skin effects in the conductors (wires) at high speed. Circulating current between parallel path or/and conductor wires are also considered in the modeling. In case of AC losses, the total stator Joule losses ($W_{\text{Stator Joule Tot.}}$) is given by:

$$W_{\text{Stator Joule Tot.}} = W_{\text{Stator DC Joule Tot.}} + W_{\text{Stator AC Joule Tot.}}$$

Each term “AC and DC” are themselves divided in two parts: the “winding active length part” (lamination part) and the “end winding part”.

$$W_{\text{Stator DC Joule Tot.}} = W_{\text{Stator DC Joule W.A.L.}} + W_{\text{Stator DC Joule E.W.}}$$
$$W_{\text{Stator AC Joule Tot.}} = W_{\text{Stator Ac Joule W.A.L.}} + W_{\text{Stator AC Joule E.W.}}$$

In the winding active length part (W.A.L), field effect, skin effect and circulating current are considered.
In the end ring part (E.W), field effect and skin effect are neglected, only circulating current are considered. This allows to identify the amount of AC losses induced by circulating current between wires of conductors (Circulating current are induced by the unbalance of impedance of wires of a conductor itself induced by the field variation in conjunction of each wire position in a conductor).

Thanks to AC losses computation, “stator winding resistance ratio” are computed for the “total resistance”, the “Winding Active Length resistance” and the “End Winding resistance”. Ratios are computed by following the below equations:

$$R_{\text{s AC/DC}} = \frac{W_{\text{Stator DC Joule Tot.}} + W_{\text{Stator AC Joule Tot.}}}{W_{\text{Stator DC Joule Tot.}}}$$

$$R_{s\ \text{w.a.l.}\ AC/DC} = \frac{W_{\text{Stator DC Joule W.A.L.}} + W_{\text{Stator AC Joule W.A.L.}}}{W_{\text{Stator DC Joule W.A.L.}}}$$

$$R_{s\ \text{e.w.}\ AC/DC} = \frac{W_{\text{Stator DC Joule E.W.}} + W_{\text{Stator AC Joule E.W.}}}{W_{\text{Stator DC Joule E.W.}}}$$

1.2.3.6 Flux density in iron

Mean and maximum values of flux density of each iron region are computed with the help of sensors in Flux® software.

1.2.3.7 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed thanks to sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

1.2.3.8 Torque

The magnetic torque exerted on a non-deformable part of the domain is computed by the virtual work method. The torque in a direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in the regional volume

The electromagnetic torque is computed over the electrical period with respect to the rotor angular position $T_{em,\theta}$.
Then, the mean value of the electromagnetic torque is computed "$T_{em,\ mean}$".
The iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em,\ mean}$," to get the corresponding mean value of the mechanical torque "$T_{mech,\ mean}$". To compute the resulting mechanical ripple torque, the mean electromagnetic torque previously computed is weighted by the ratio of the mean value of the mechanical torque ($T_{mech,\ mean}$) and the mean value of the original electromagnetic torque ($T_{em,\ mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,mean}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

1.2.3.9 Flux in airgap

The airgap flux density is computed with a sensor which is defined in the static part of the airgap under a tooth in Flux® software. The resulting signal is obtained over an electric period. The average and the peak value of the flux density are also computed. The harmonic analysis of the phase voltage is done to evaluate the harmonics content.

1.2.3.10 Phase voltage

The phase voltage is computed with a sensor defined in the electrical circuit in Flux® software. The resulting signal is obtained over an electric period. The harmonic analysis of the phase voltage is done to evaluate the harmonics content.

1.2.3.11 Phase current

The phase current is computed with a sensor defined in the electrical circuit in Flux® software. The resulting signal is obtained over an electric period. The harmonic analysis of the phase voltage is done to evaluate the harmonics content very useful in case of delta winding coupling.

1.2.4 Limitation of thermal computations - Advice for use

Notes:

1) Setting a skew angle modifies the electromagnetic performance of the machine, including the losses.
For electromagnetic/thermal iterative solving, the losses are then considered as inputs of the thermal computation.
This means that in "Iterative" solving modes, the temperatures reached in the machine will change depending on the skew angle in input.

2) The resistance network identification of a machine is always done without any skew angle.
This can bring some inaccuracy in the results for highly skewed machines.

3) For additional information, please refer to the document: MotorFactory_SMPM_IOR_3PH_Test_Introduction – section “Limitation of thermal computations – Advice for use”

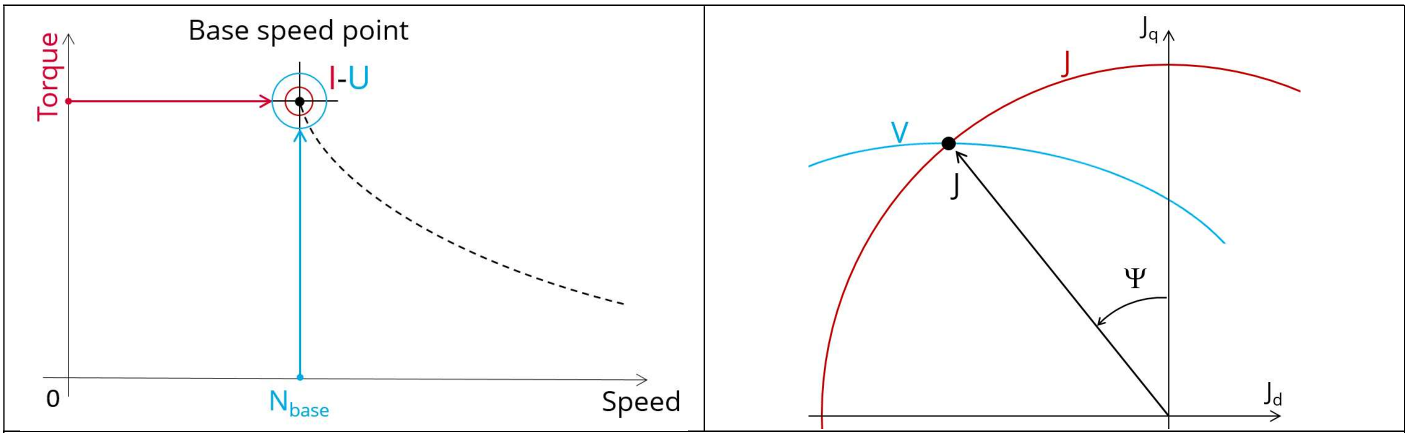
2 WORKING POINT – SINE WAVE – MOTOR – T, N

2.1 Overview

2.1.1 Positioning and objective

The aim of the test “**Working point – Sine wave – Motor – T, N”** is to characterize the behavior of the machine when operating at the working point which is targeted by the user. It corresponds to the base point at a targeted useful torque and speed.
The working point torque-speed is defined by considering the targeted input values T, N (useful torque, speed).

This test allows defining the required line-line voltage and line current to reach the targeted useful torque and speed for the considered command mode (MTPV, MTPA or maximum efficiency).



Working point – Sine wave – Motor – T,N - Illustration

The results of this test give an overview of the electromagnetic analysis of the motor considering the machine topology.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed.
The magnetic flux density is also computed in every region of the machine magnetic circuit to evaluate the design.

Note: In FluxMotor® terminology, the constant torque last working point of the torque-speed curve is called “Base speed point”, only if it is obtained for the maximum allowed line-line voltage and maximum line current. If it is not the case, we called as “Corner speed point”.

The following table helps to classify the test “Working point – Sine wave – Motor – T, N”.

Family	Working point
Package	Sine wave
Convention	Motor
Test	T, N

Positioning of the test “Working point – Sine wave – Motor – T, N”

2.2 Main principles of computations

2.2.1 Overview

The aim of this test is to give a good overview of the electromagnetic potential of the machine by characterizing the base speed point according to the targeted mechanical torque and speed set by the user.
In addition, ripple torque at the base speed point is computed.

Several computation processes are involved:

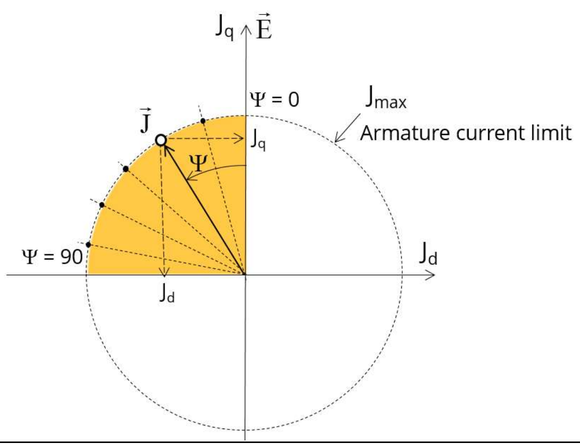
- Base speed point
- Ripple torque
- Electromagnetic behavior
- Maximum speed estimation

2.2.2 Base speed point

2.2.2.1 Initialization of the computation

First, it is needed to compute the range of current to be able to reach the targeted mechanical torque.
A loop considering the values of current is done. For each value of current the maximum mechanical torque in function of the control angle is computed. When the value of the mechanical torque is very close to the targeted mechanical torque, the loop is then stopped.

The computation method used inside the loop is close than the one used for the test “Working point – Sine Wave – Motor – U-I” described in the section 3 (Working point – Sine wave – Motor –) .
However, in this case, the computation of the base speed point is replaced by the computation of the maximum mechanical torque versus the control angle.

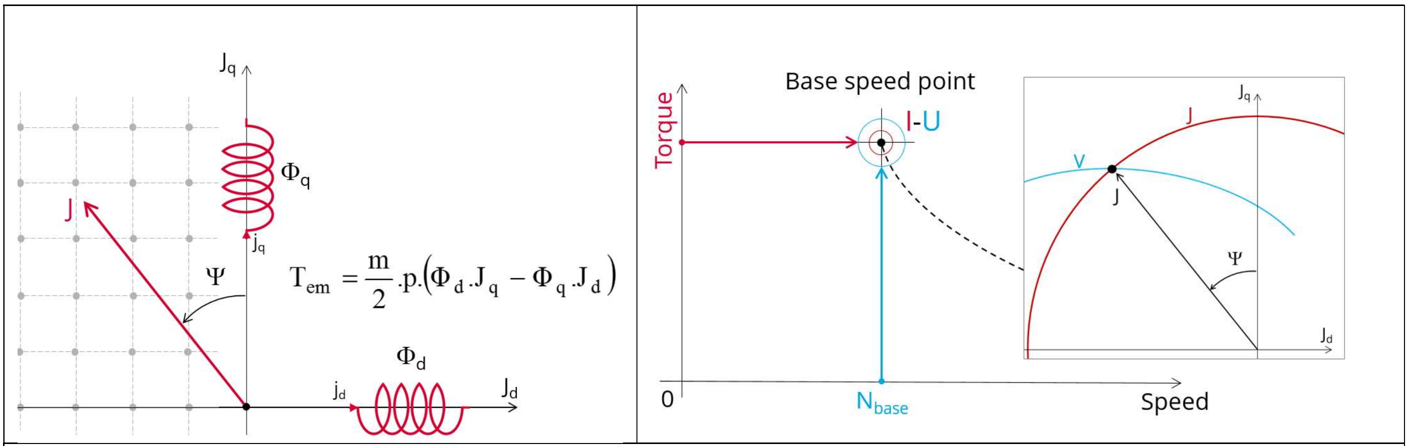


Discretization of the circle corresponding to J_{max}.

2.2.2.2 Computation of the base speed point

Thanks to the identification of the range of current in which the mechanical torque is reachable, the computation of the base speed point is done with the same computation method used for the test “Performance mapping - Sine wave - Motor – Efficiency Map”.

The computation method depends also on the chosen command.



Computation method of the base speed point – Test “Working point – Sine Wave – Motor – T-N”

Note: We remind that for the base speed point, both commands “MTPA and MTPV” lead to the same results.
In fact, the base speed point corresponds to the working point which maximizes the mechanical torque at maximum current and at maximum voltage. Following this, we easily understand that we will obtain same results with MTPV or with MTPA.

However, the maximum speed estimation depends on whether MTPV or MTPA command mode is chosen.

2.2.3 Electromagnetic behavior

2.2.3.1 Introduction

Electromagnetic behavior computation method used depends on if ripple torque analysis is set to “Yes” or to “No”:

- “Yes” is selected: The analysis of the electromagnetic behavior is done over one ripple torque period (when torque ripple computation is not performed).
- “No” is selected: The analysis of the electromagnetic behavior is done with a dedicated static computation (1 rotor position to be considered) done for the computed working point (with line current, control angle and speed obtained for the working point).

2.2.3.2 Flux in airgap

The flux in the airgap is always computed thanks to the dedicated static computation of the working point.

The airgap flux density is computed along an airgap path in Flux® software. The resulting signal is obtained over at least an electric period. The average and the peak value of the flux density are also computed. A harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic flux density.

2.2.3.3 Flux density in iron

Mean and maximum values of each flux density in regions are computed thanks to sensors in Flux® software.

2.2.3.4 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed thanks to sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

2.2.4 Ripple torque

A specific computation is performed to determine the rate of ripple torque precisely.
Considering J_d and J_q at the base speed point, a computation is performed over one ripple torque period by using Finite Element modelling (Flux® software – Magnetostatic application).
Many computation points are considered over the ripple torque period (advanced user input: **No. comp. / ripple period**).
The following steps are performed to determinate the mechanical torque.

2.2.4.1 Original computation of the electromagnetic torque

The magnetic torque exerted on a non-deformable part of the study domain is computed by the virtual work method. The torque in a given direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in a volume region

The electromagnetic ripple torque is computed over the ripple torque period versus the rotor angular position $T_{em,\theta}$. The mean value "$T_{em, mean}$" is computed

2.2.4.2 Mechanical ripple torque based on Park's model

The mechanical ripple torque must be computed at the base speed.
First, we compute the electromagnetic torque "$T_{em, Park}$" with Park's model:

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

Then, the iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em, Park}$" to get the corresponding mean value of the mechanical torque "$T_{mech, Park}$".

2.2.4.3 Resulting mechanical torque versus rotor angular position

To compute the resulting mechanical ripple torque, the original electromagnetic torque previously computed is weighted by the ratio of the mean value of the mechanical torque based on Park's model ($T_{mech, Park}$) and of the mean value of the original electromagnetic ripple torque ($T_{em, mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,Park}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

Warning: When the ripple torque computation is not requested, the computation of the working point is performed by considering only one position within the electrical period. It means that all the data characterizing the behavior of the machine can change based on the selection of ripple torque (Yes/No).
Flux density in magnetic circuit and the magnet behavior will be more accurately computed when the computation of the ripple torque will be requested.

2.2.5 Maximum speed estimation

The maximum speed estimation is based on obtained results at the base speed point. Thanks to Park model voltage equations (phase resistance neglected but End winding inductance considered) and computed flux linkage at the base speed point, a linear assumption is done on the flux to estimate the maximum speed. Then, a reduction factor is applied to minimize the linear assumption impact.
This computation is performed by considering the command modes (MTPV, MTPA…).

According to assumptions, the aim is just to give the order of magnitude of the reachable maximum speed of the motor.

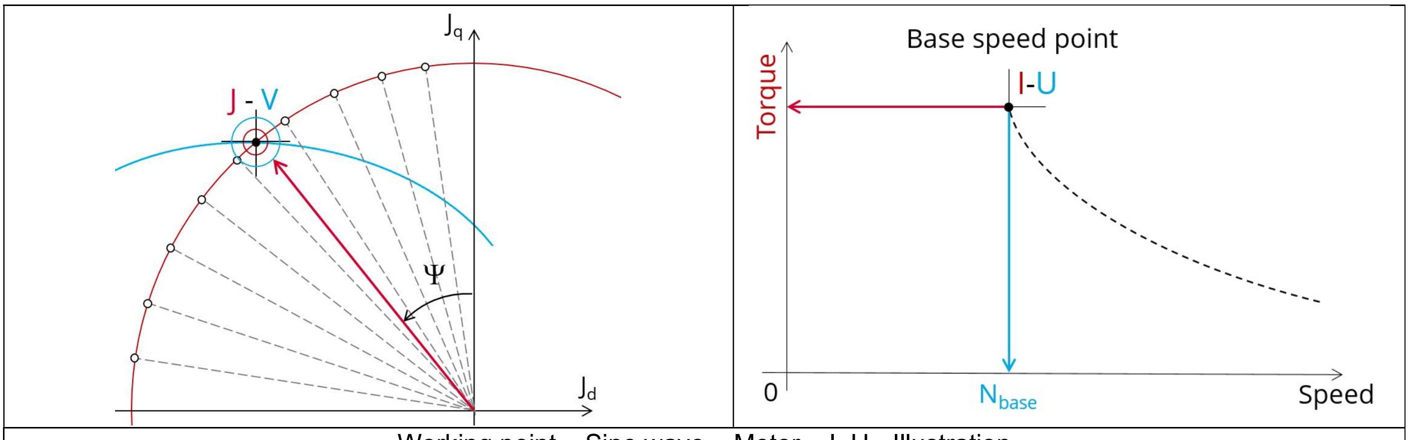
3 WORKING POINT – SINE WAVE – MOTOR – I, U

3.1 Overview

3.1.1 Positioning and objective

The aim of the test “**Working point – Sine wave – Motor – I, U”** is to characterize the behavior of the machine when operating at the working point which is targeted by the user. It corresponds to the base point at the imposed maximum line current and maximum Line-Line voltage.

The base point of the torque-speed curve is defined by considering the targeted input values I, U (Voltage, current). Then, this test allows deducing the performance for this working point.



Working point – Sine wave – Motor – I, U - Illustration

The results of this test give an overview of the electromagnetic analysis of the motor considering the machine topology.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed.
The magnetic flux density is also computed in every region of the machine’s magnetic circuit to evaluate the design.
In addition, ripple torque at the base speed point is computed.

The following table helps to classify the test “Working point – Sine wave – Motor – I, U”.

Family	Working point
Package	Sine wave
Convention	Motor
Test	I, U

Positioning of the test “Working point – Sine wave – Motor – I, U”

3.2 Main principles of computation

3.2.1 Introduction

The aim of this test is to give a good overview of the electromagnetic potential of the machine by characterizing the base speed point according to the maximum Line-Line voltage and the maximum line current set by the user.
In addition, ripple torque at the base speed point is computed.

For this purpose, several computation processes are involved:

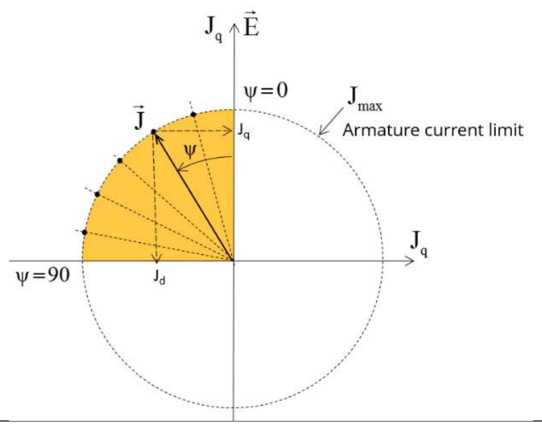
- Base speed point
- Electromagnetic behavior
- Ripple torque
- Maximum speed estimation

3.2.2 Base speed point

The base speed point of the torque speed curve corresponds to the obtained working point by considering the maximum allowed values of line current and line-line voltage ($I_{max.}$ and $U_{max.}$).
The quarter of circle corresponding to the maximum phase current in the J_d-J_q plane is discretized by considering the number of computations for control angle (Ψ) which is a user input parameter.

Several quantities, like the flux in the coils and flux density in regions (teeth and yoke to be able to compute iron losses) are computed as a function of the control angle Ψ.
These computations are done by using Finite Element Modelling (Flux® software – Magnetostatic application).

- Φd = f (Ψ)
- Φq = f (Ψ)
- B = f (Ψ)



Discretization of the circle corresponding to $J_{max.}$

Then an optimization process is performed to get the base speed point which corresponds to the working point at maximum line current and maximum line-line voltage: $I = I_{max.}$ and $U = U_{max.}$.

The resulting data are called "general data" and include:

- The control angle (Ψ) and thereby Jd and Jq
- The base speed
- The electrical frequency
- The torque
- The voltage components (Vd, Vq)
- ….

In addition, the power balance is done and machine constant for the base speed point "kT" is computed.

For more details, please refer to the document: MotorFactory_SMPM_IOR_3PH_Test_Introduction – section dealing with "Electrical machine – Theoretical equations".

3.2.3 Electromagnetic behavior

3.2.3.1 Introduction

Used method of electromagnetic behavior computation depends on if ripple torque analysis is set to "Yes" or to "No":

- "Yes" is selected: The analysis of the electromagnetic behavior is done over one ripple torque period (when torque ripple computation is not performed).
- "No" is selected: The analysis of the electromagnetic behavior is done with a dedicated static computation (1 rotor position to be considered) done for the working point computed (with line current, control angle and speed obtained for the working point).

3.2.3.2 Flux in airgap

The flux in the airgap is always computed thanks to the dedicated static computation of the working point.

The airgap flux density is computed along a path in the airgap in Flux® software. The resulting signal is obtained over at least an electric period. The average and the peak value of the flux density are also computed. A harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic of the flux density.

3.2.3.3 Flux density in iron

Mean and maximum values of flux density of each iron region are computed thanks to sensors in Flux® software.

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Mean values of flux density and magnetic field inside the magnets are computed thanks to sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

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Many computation points are considered over the ripple torque period (advanced user input: **No. comp. / ripple period**).
The following steps are performed to determinate the mechanical torque.

3.2.4.1 Original computation of the electromagnetic torque

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3.2.4.2 Mechanical ripple torque based on Park's model

The mechanical ripple torque must be computed at the base speed.
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$$T_{em,Park} = \frac{m}{2} \times p \times \left(\Phi_d \times J_q - \Phi_q \times J_d\right)$$

Then, the iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em, Park}$" to get the corresponding mean value of the mechanical torque "$T_{mech, Park}$".

3.2.4.3 Resulting mechanical torque versus rotor angular position

To compute the resulting mechanical ripple torque, the original electromagnetic torque previously computed is weighted by the ratio of the mean value of the mechanical torque based on Park's model ($T_{mech, Park}$) and of the mean value of the original electromagnetic ripple torque ($T_{em, mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,Park}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

Warning: When the ripple torque computation is not requested, the computation of the working point is performed by considering only one position within the electrical period. It means that all the data characterizing the behavior of the machine can change based on the selection of ripple torque (Yes/No).
Flux density in magnetic circuit and the magnet behavior will be more accurately computed when the computation of the ripple torque will be requested.

3.2.5 Maximum speed estimation

The maximum speed estimation is based on results obtain at the base speed point. Thanks to Park model voltage equations (phase resistance neglected but End winding inductance considered) and flux linkage computed at the base speed point, a linear assumption is done on the flux to estimate the maximum speed. Then, a reduction factor is applied to minimize the linear assumption impact.
This computation is performed by considering the command mode (MTPV, MTPA…).

According to assumptions, the aim is just to give the order of magnitude of the maximum speed reachable by the motor.

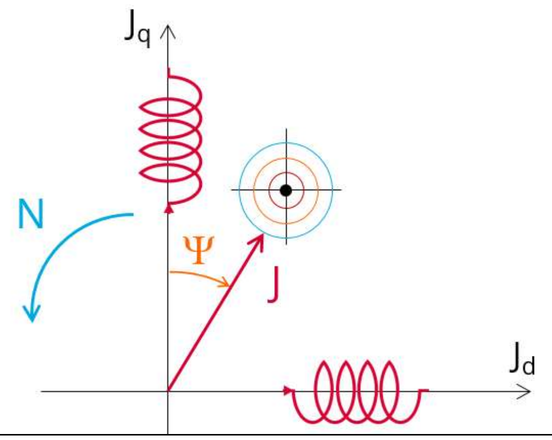
4 WORKING POINT – SINE WAVE – GENERATOR – I, Ψ, N

4.1 Overview

4.1.1 Positioning and objective

The aim of the test "**Working point – Sine wave – Generator – I, Ψ, N"** is to characterize the behavior of the machine when operating at the targeted input values I, Ψ, N (Magnitude of current, Control angle, Speed).
These three inputs are enough to impose a precise working point.

For instance, a working point on the efficiency map can be chosen, by identifying the current, the control angle and the speed with different curves or maps displayed in the "Performance mapping / Sine wave / Generator / Efficiency map" test. Then, the "Working point – Sine wave – Generator – I, Ψ, N" test allows to compute the performance for this working point.



"Working point – Sine wave – Generator – I, Ψ, N" illustration

The results of this test give an overview of the electromagnetic analysis of the machine considering its topology.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed. The generator convention is used to build the model.
The magnetic flux density is also computed in every region of the machine magnetic circuit to evaluate the design.

When both the following conditions are met this test allows to perform electromagnetic computations with coupled thermal analysis.:

- The type of machine is Synchronous Machine with Permanent Magnets with Inner rotor.
- Iterative thermal solving modes can be selected.

Two computation modes are available:
- "Fast computation mode" is perfectly suited for the pre-design step (Hybrid model based on Magneto-Static Finite Element computations and Park transformation theory)
- "Accurate computation mode" is perfectly suited for the final design step (Pure Finite Element modeling based on transient computations)

It also gives the capability to make comparisons between the results obtained from the measurements and those obtained with FluxMotor®.
The following table helps to classify the test "Working point – Sine wave – Generator – I, Ψ, N".

Family	Working point
Package	Sine wave
Convention	Generator
Test	I, Ψ, N

Positioning of the test "Working point – Sine wave – Generator – I, Ψ, N"

4.2 Main principles of computation

4.2.1 Introduction

The aim of this test in generator convention is to give a good overview of the electromagnetic potential of the machine by characterizing the working point according to the line current, control angle and speed set by the user.
In addition, ripple torque at the working point is also computed.

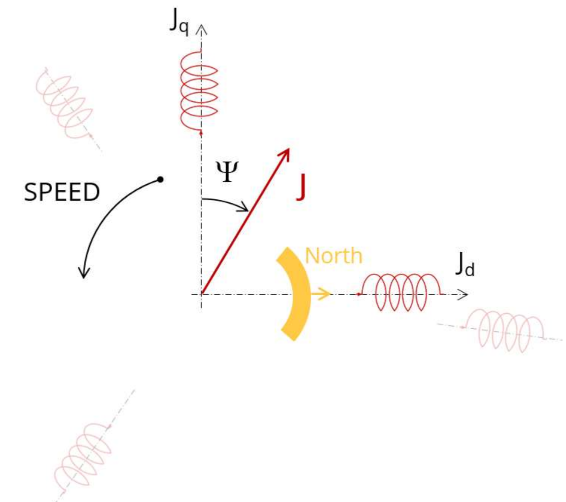
Two computation modes are available:

- "Fast computation mode" is perfectly suited for the pre-design step to explore the space of solutions quickly and easily (Hybrid model based on magnetostatic FE computations and Park transformation).
-
- "Accurate computation mode" is perfectly suited for the final design step because it allows getting more accurate results and to compute additional quantities like the AC losses in winding, rotor iron losses and Joule losses in magnets (Pure FE model based on transient computations)

4.2.2 Fast computation mode

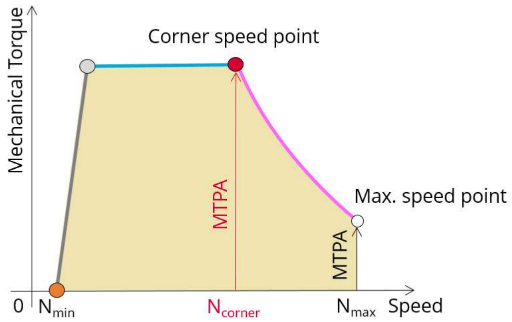
4.2.2.1 Working point - Definition

To compute the working point, the principle consists of positioning the magnet axis towards the reference phase axis by considering the targeted control angle.
At the same time, the targeted line current and speed are imposed.
Then, the resulting behavior of the machine can be simulated, and all the main electromagnetic characteristics of the machine can be deduced by using Park's transformation and associated electric equations.



Magnet axis and reference phase axis Positioning – Generator convention

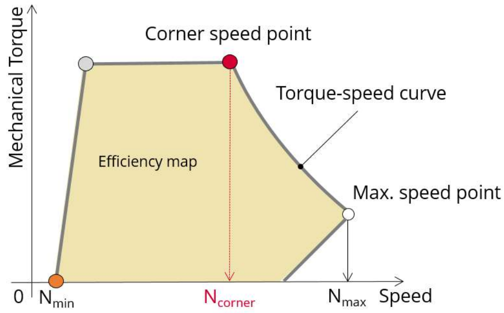
Note: In generator operating mode, mechanical power provided on the shaft must be higher than losses otherwise the electrical power is negative, and no current can be supplied by the generator.
It is why, at low speed, for each value of mechanical torque, a minimum speed always exists to be able to supply electrical current.
In FluxMotor®, this limit at no-speed is called "Minimum speed point".



Torque speed curve with MTPA command mode – Generator operating mode

High discretization of speed

Note: When the machine has high losses at high speed some working points can be unreachable. Resulting torque-speed curves and maps look like as the following figure:



Machine with high losses at high speed - Torque speed curves and maps with MTPA command mode after correction of unavailable working point

So, when the targeted working point is in an unreachable zone (left or right white area of the figure above), a warning message is issued by FluxMotor® and the efficiency is set at " - ". All other computed results are available and can be analyzed (power balance) for targeting a reachable working point.

4.2.2.2 Electromagnetic behavior – General information

The method used for computation of electromagnetic behavior depends on if ripple torque analysis is set to "Yes" or "No":

- "Yes" is selected: The analysis of the electromagnetic behavior is done over one ripple torque period (when torque ripple computation is not performed).
- "No" is selected: The analysis of the electromagnetic behavior is done with a dedicated static computation (1 rotor position to be considered) done for the working point computed (with line current, control angle and speed obtained for the working point).

4.2.2.3 Flux in airgap

The flux in the airgap is always computed thanks to the dedicated static computation of the working point.

The airgap flux density is computed along an airgap path in Flux® software. The resulting signal is obtained for at least an electric period. The average and the peak value of the flux density are also computed. The harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic of the flux density.

4.2.2.4 Flux density in iron

Mean and maximum values of flux density of each iron region are computed with the help of sensors in Flux® software.

4.2.2.5 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed with the help of sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

4.2.2.6 Ripple torque

A specific computation is performed to determine the rate of ripple torque precisely.
Considering J_d and J_q at the base speed point, a computation is performed over one ripple torque period by using Finite Element modelling (Flux® software – Magnetostatic application).
Many computation points are considered over the ripple torque period (advanced user input: **No. comp. / ripple period**).
The following steps are performed to determinate the mechanical torque.

1) Original computation of the electromagnetic torque

The magnetic torque exerted on a non-deformable part of the domain is computed by the virtual work method. The torque in a given direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in the regional volume

The electromagnetic ripple torque is computed over the ripple torque period with respect of the rotor angular position $T_{em,\theta}$. The mean value "$T_{em,\ mean}$" can also be computed.

2) Mechanical ripple torque based on Park's model

The mechanical ripple torque must be computed at the base speed.
First, we compute the electromagnetic torque "$T_{em,\ Park}$" with Park's model:

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

Then, the iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em,\ Park}$ " to get the corresponding mean value of the mechanical torque "$T_{mech,\ Park}$".

3) Resulting mechanical torque versus rotor angular position

To compute the resulting mechanical ripple torque, the original electromagnetic torque computed previously is weighted by the ratio of the mean value of the mechanical torque based on Park's model ($T_{mech,\ Park}$) and of the mean value of the original electromagnetic ripple torque ($T_{em,\ mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,Park}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

Warning: When the ripple torque computation is not requested, the computation of the working point is performed by considering only one position within the electrical period. It means that all the data characterizing the behavior of the machine can change based on the selection of ripple torque (Yes/No).
Flux density in magnetic circuit and the magnet behavior will be more accurately computed when the computation of the ripple torque will be requested.

4.2.3 Accurate computation mode

4.2.3.1 Working point - Definition

Working point computation is based on a transient magnetic finite element simulation over a half, one or several electrical periods for a given set of inputs: control angle, line current and speed defined as for the Fast computation mode.
Thus, all the main electromagnetic characteristics of the machine can be deduced accurately.

4.2.3.2 Electromagnetic behavior – General information

All the main quantities are directly computed from the Flux® software in the framework of a transient magnetic finite element simulation.

4.2.3.3 Iron losses

Iron losses (stator and rotor) are computed, thanks to the "transient modified Bertotti model" in Flux® software.

4.2.3.4 Magnet losses

Magnet losses are computed thanks to the sensors defined for each corresponding region in Flux® software.

4.2.3.5 Stator Joule winding losses

The stator's DC Joule losses are always computed.

However, if AC losses analysis is set to "FE-One phase" or "FE-all phase" stator AC Joule losses are computed in addition to stator's DC Joule losses.

FE-One phase: AC losses are computed with only one phase modeled for solid conductors (wires) inside the slots. The two other ones are modeled with coil regions. Thus, AC losses in winding are computed with a lower computation time than if all the phases were modeled with solid conductors. However, this can have a little impact on the accuracy of results because we have supposed that the magnetic field is not impacted by the modeling assumption.

FE-All phase: AC losses are computed, with all phases modeled with solid conductors (wires) inside the slots. This computation method gives the best results in terms of accuracy, but with a higher computation time.

FE-Hybrid: AC losses in winding are computed without representing the wires (strands, solid conductors) inside the slots.
Since the location of each wire is accurately defined in the winding environment, sensors evaluate the evolution of the flux density close each wire. Then, a postprocessing based on analytical approaches computes the resulting current density inside the conductors and the corresponding Joule losses.
With the "FE-Hybrid" option the accuracy of results is good especially when the wire size is small (let's say wire diameter lower than 2.5 mm). However, this can have a little impact on the accuracy of results because we have supposed that the magnetic field is not impacted by the modeling assumption.

In FluxMotor®, stator AC Joule losses corresponds to the additional losses induced by fields and skin effects in the conductors (wires) at high speed. The circulating current between parallel path or/and conductor wires are also considered in the modeling. In case of AC losses, the total stator Joule losses ($W_{\text{Stator Joule Tot.}}$) is given by:

$$W_{\text{Stator Joule Tot.}} = W_{\text{Stator DC Joule Tot.}} + W_{\text{Stator AC Joule Tot.}}$$

Each term "AC and DC" are themselves divided in two parts: the "winding active length part" (lamination part) and the "end winding part".

$$W_{\text{Stator DC Joule Tot.}} = W_{\text{Stator DC Joule W.A.L.}} + W_{\text{Stator DC Joule E.W.}}$$
$$W_{\text{Stator AC Joule Tot.}} = W_{\text{Stator Ac Joule W.A.L.}} + W_{\text{Stator AC Joule E.W.}}$$

In the winding active length part (W.A.L), field effect, skin effect and circulating current are considered.
In the end ring part (E.W), field effect and skin effect are neglected, only circulating current are considered. This allows to identify the amount of AC losses induced by circulating current between wires of conductors (Circulating current are induced by the unbalance of impedance of wires of a conductor itself induced by the field variation in conjunction of each wire position in a conductor).

Thanks to AC losses computation, "stator winding resistance ratio" are computed for the "total resistance", the "Winding Active Length resistance" and the "End Winding resistance". Ratios are computed by following the below equations:

$$R_{\text{s AC/DC}} = \frac{W_{\text{Stator DC Joule Tot.}} + W_{\text{Stator AC Joule Tot.}}}{W_{\text{Stator DC Joule Tot.}}}$$

$$R_{\text{s w.a.l. AC/DC}} = \frac{W_{\text{Stator DC Joule W.A.L.}} + W_{\text{Stator AC Joule W.A.L.}}}{W_{\text{Stator DC Joule W.A.L.}}}$$

$$R_{\text{s e.w. AC/DC}} = \frac{W_{\text{Stator DC Joule E.W.}} + W_{\text{Stator AC Joule E.W.}}}{W_{\text{Stator DC Joule E.W.}}}$$

4.2.3.6 Flux density in iron

Mean and maximum values of flux density of each iron region are computed with the help of sensors in Flux® software.

4.2.3.7 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed with the help of sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

4.2.3.8 Torque

The magnetic torque exerted on a non-deformable part of the domain is computed by the virtual work method. The torque in a direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in the regional volume

The electromagnetic torque is computed over the electrical period with respect to the rotor angular position $T_{em,\theta}$.
Then, the mean value of the electromagnetic torque is computed "$T_{em,\ mean}$". The iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em,\ mean}$," to get the corresponding mean value of the mechanical torque "$T_{mech,\ mean}$". To compute the resulting mechanical ripple torque, the mean electromagnetic torque previously computed is weighted by the ratio of the mean value of the mechanical torque ($T_{mech,\ mean}$) and the mean value of the original electromagnetic torque ($T_{em,\ mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,mean}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

4.2.3.9 Flux in airgap

The airgap flux density is computed with a sensor which is defined in the static part of the airgap under a tooth in Flux® software. The resulting signal is obtained over an electric period. The average and the peak value of the flux density are also computed. The harmonic analysis of the phase voltage is done to evaluate the harmonics content.

4.2.3.10 Phase voltage

The phase voltage is computed with a sensor defined in the electrical circuit in Flux® software. The resulting signal is obtained over an electric period. The harmonic analysis of the phase voltage is done to evaluate the harmonics content.

4.2.3.11 Phase current

The phase current is computed with a sensor defined in the electrical circuit in Flux® software. The resulting signal is obtained over an electric period. The harmonic analysis of the phase voltage is done to evaluate the harmonics content very useful in case of delta winding coupling.

4.2.4 Limitation of thermal computations - Advice for use

Notes:

1) Setting a skew angle modifies the electromagnetic performance of the machine, including the losses.
For electromagnetic/thermal iterative solving, the losses are then considered as inputs of the thermal computation.
This means that in "One iteration" or "Iterative" solving modes, the temperatures reached in the machine will change depending on the skew angle in input.

2) The resistance network identification of a machine is always done without any skew angle.
This can bring some inaccuracy in the results for highly skewed machines.

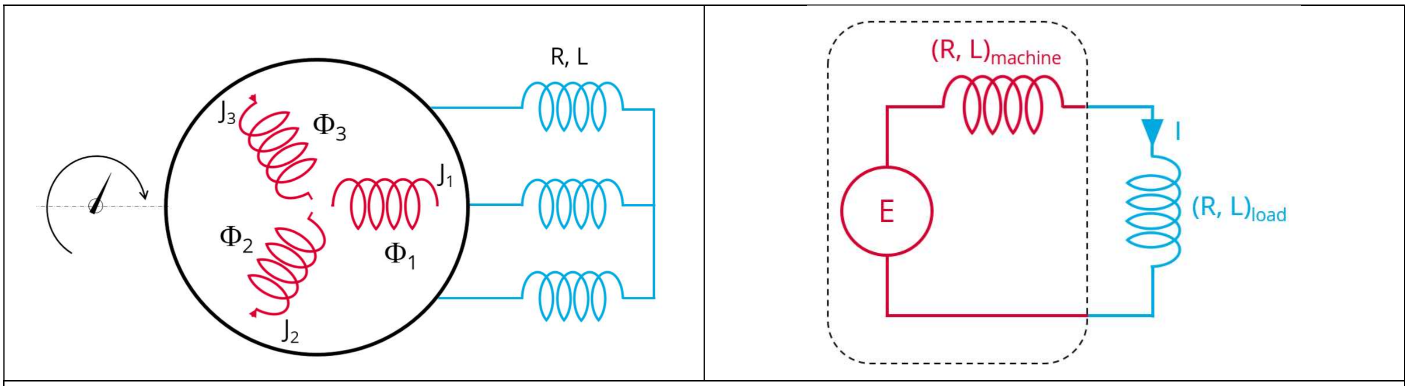
3) For additional information, please refer to the document: MotorFactory_SMPM_IOR_3PH_Test_Introduction – section "Limitation of thermal computations – Advice for use"

5 WORKING POINT – SINE WAVE – GENERATOR – R, L LOAD & SPEED

5.1 Overview

5.1.1 Positioning and objective

The aim of the test "**Working point – Sine wave – Generator – R-L-N"** is to characterize the generator performance when operating with a star-connected 3-phase R, L load at the targeted speed N.



"Working point – Sine wave – Generator – R, L, N " illustration

The results of this test give an overview of the electromagnetic analysis of the machine considering the machine topology.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed. The considered convention is the generator one.
The magnetic flux density is also computed in every region of the machine magnetic circuit to evaluate the design.

The following table helps to classify the test "Working point – Sine wave – Generator – R, L, N".

Family	**Working point**
Package	Sine wave
Convention	Generator
Test	R, L, N

Positioning of the test "Working point – Sine wave – Generator – R, L, N"

5.2 Main principle of computation

5.2.1 Steady state behavior

The aim of this test is to define the behavior of the generator when a star connected 3-phase load (resistance R and inductance L in series) is put at its terminal ends. It gives a good overview of the electromagnetic behavior of the machine by characterizing the resulting working point.

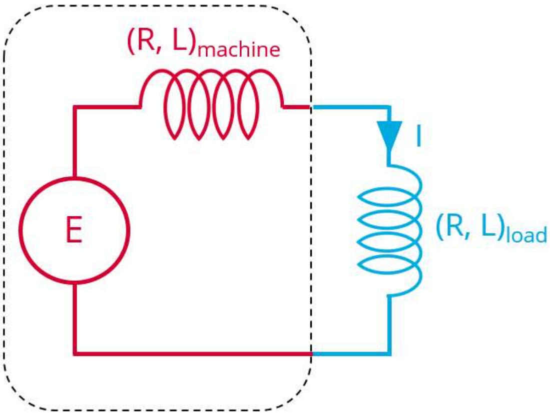
The principle of this test is to iterate on the working point occurring in the generator (current in DQ area), until converging on the working point corresponding to the R-L load plugged to the generator.

The convergence process is driven by an equivalent circuit of the machine connected to the load. In each iteration, finite element software Flux is called to compute the magnetic behavior of the machine and set accurately the parameters of the equivalent circuit.

After the needed iterations, the process gives the magnetic behavior of the machine connected to the load, and all data corresponding to this working point.

All the equations are written by considering the generator convention.

For more information, please refer please refer to the document: MotorFactory_SMPM_IOR_3PH_Test_Introduction – section "Electrical machine – Theoretical equations" where the general presentation of the machine characteristics is presented.



Electrical equation loop to be solved

5.2.2 Electromagnetic behavior

5.2.2.1 Introduction

Used method of electromagnetic behavior computation depends on if ripple torque analysis is set to "Yes" or to "No":

- "Yes" is selected: The analysis of the electromagnetic behavior is done over one ripple torque period (when torque ripple computation is not performed).
- "No" is selected: The analysis of the electromagnetic behavior is done with a dedicated static computation (1 rotor position to be considered) done for the working point computed (with line current, control angle and speed obtained for the working point).

5.2.2.2 Flux in airgap

The flux in the airgap is always computed thanks to the dedicated static computation of the working point.

The airgap flux density is computed along a path in the airgap in Flux® software. The resulting signal is obtained over at least an electric period. The average and the peak value of the flux density are also computed. A harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic of the flux density.

5.2.2.3 Flux density in iron

Mean and maximum values of flux density of each iron region are computed thanks to sensors in Flux® software.

5.2.2.4 Magnet behavior

Mean values of flux density and magnetic field inside the magnets are computed thanks to sensors in Flux® software. Based on these results, demagnetization rate of the magnets is computed.

5.2.3 Ripple torque

A specific computation is performed to precisely determine the rate of ripple torque.
Considering J_d and J_q at the base speed point, a computation is performed over one ripple torque period by using Finite Element modelling (Flux® software – Magnetostatic application).
Many computation points are considered over the ripple torque period (advanced user input: **No. comp. / ripple period**).
The following steps are performed to determinate the mechanical torque.

5.2.3.1 Original computation of the electromagnetic torque

The magnetic torque exerted on a non-deformable part of the study domain is computed by the virtual work method. The torque in a given direction is obtained by deriving the system energy with respect to a virtual displacement of the part in this direction.
The magnetic torque T_{em} is given by the following derivative:

$$T_{em} = -\frac{\partial W_m}{\partial \theta}$$

$\partial\theta$ = elementary angular displacement,
W_m = magnetic energy in a volume region

The electromagnetic ripple torque is computed over the ripple torque period versus the rotor angular position $T_{em,\theta}$. The mean value "$T_{em, mean}$" is computed

5.2.3.2 Mechanical ripple torque based on Park's model

The mechanical ripple torque must be computed at the base speed.
First, we compute the electromagnetic torque "$T_{em, Park}$" with Park's model:

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

Then, the iron loss torque, the mechanical loss torque and the additional loss torque are subtracted from "$T_{em, Park}$" to get the corresponding mean value of the mechanical torque "$T_{mech, Park}$".

5.2.3.3 Resulting mechanical torque versus rotor angular position

To compute the resulting mechanical ripple torque, the original electromagnetic torque previously computed is weighted by the ratio of the mean value of the mechanical torque based on Park's model ($T_{mech,\ Park}$) and of the mean value of the original electromagnetic ripple torque ($T_{em,\ mean}$).

$$T_{mech.,\theta} = T_{em,\theta} \times \frac{T_{mech,Park}}{T_{em,mean}}$$

The peak-peak value of the mechanical ripple torque is then computed. The rate of ripple torque is deduced as a percentage or per unit of the nominal torque.

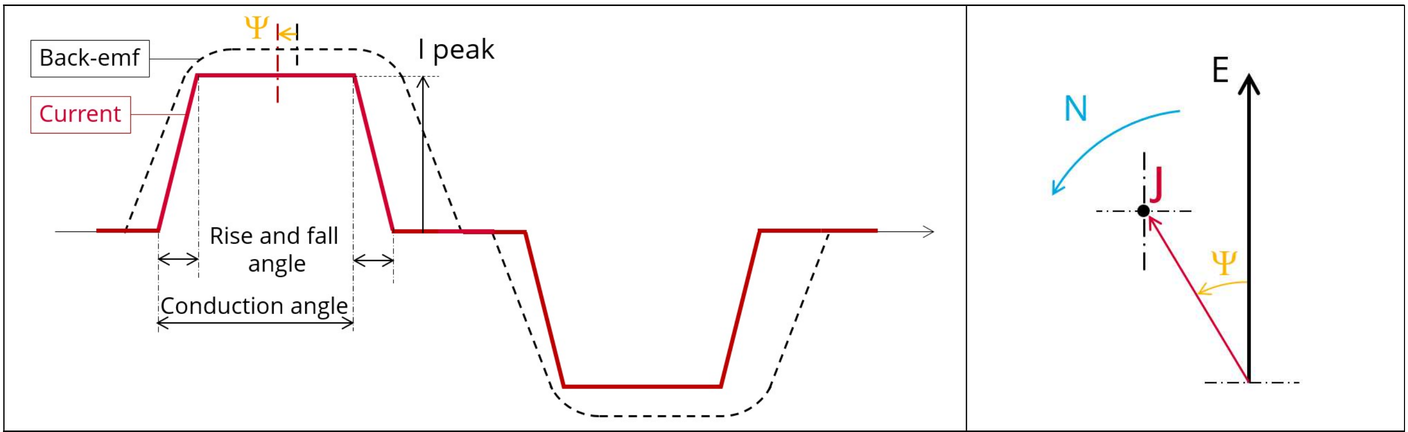
Warning: When the ripple torque computation is not requested, the computation of the working point is performed by considering only one position within the electrical period. It means that all the data characterizing the behavior of the machine can change based on the selection of ripple torque (Yes/No).
Flux density in magnetic circuit and the magnet behavior will be more accurately computed when the computation of the ripple torque will be requested.

6 WORKING POINT – SQUARE WAVE – MOTOR – FORCED I

6.1 Overview

6.1.1 Positioning and objective

The aim of the test "**Working point – Square wave – Motor – Forced I"** is to characterize the behavior of the machine when operating with a forced current defining a square wave drive.
A parameterized trapezoidal shape current defines the line current.
The control angle between the back-emf and the phase current, the value of current and the imposed speed induce the resulting working point. Then, the main corresponding performance are computed and displayed.



Working point – Square wave – Motor – Forced I - Illustration

All the results are computed from a Finite Element Analysis (Flux) - Transient application. The results of this test give an overview of the electromagnetic behavior of the considered motor.
The general data of the machine, like machine constants, power balance and magnet behavior are computed and displayed.
The magnetic flux density is also computed in every region of the machine magnetic circuit to evaluate the design.

The following table helps to classify the test "Working point – Square wave – Motor – Forced I".

Family	**Working point**
Package	Square wave
Convention	Motor
Test	Forced I

Positioning of the test "Working point – Square wave – Motor – Forced I"

Warning: When running the test "Working point – Square wave – Motor – Forced I" with a delta winding connection. Two electrical periods are considered for reaching a steady state behavior of the motor. However, sometimes two periods could not be enough to get a good convergence of our process.

6.2 Main principles of computation

6.2.1 Introduction

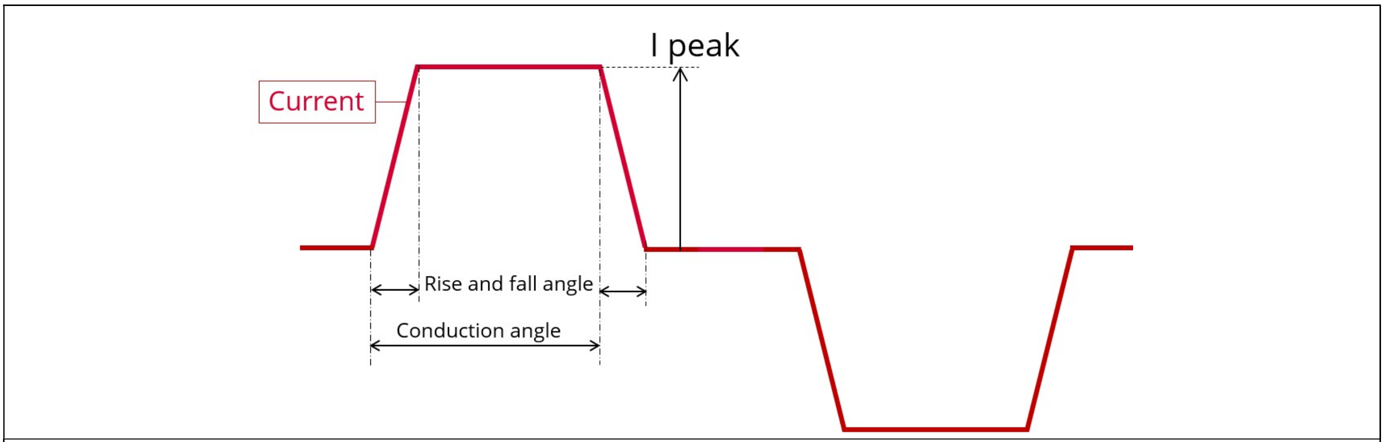
The aim of this test is to give a good overview of the electromagnetic potential of the machine when powered by a square wave current.

Several computation processes are involved:

- Working point
- Computation of iron losses
- Computation of magnet losses

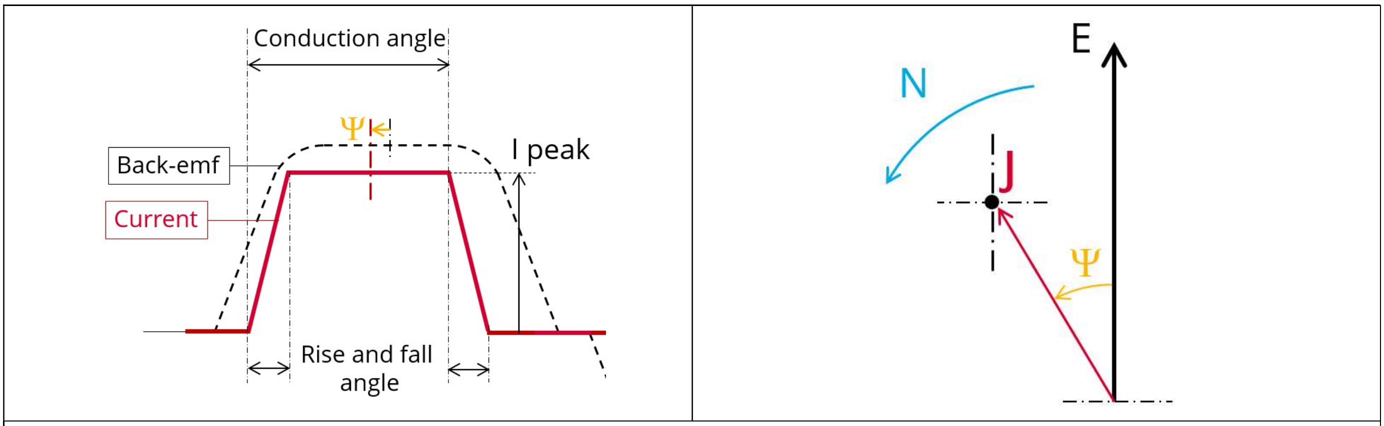
6.2.2 Working point

The shape of the current is modelled by a parameterized trapezoidal profile.
Indeed, slopes are added on this square wave current to fit the reality, where a pure square wave current has no physical meaning (it would correspond to an infinite voltage).
The definition of the trapezoidal shape of the current is described on the following figure.



Parameters defining the trapezoidal shape of the current

The principle of imposing the control angle in this test consists in positioning the magneto-motive force (MMF) according to the magnet axis already aligned and locked with d-axis of reference phase axis. The relative angular position between them is the targeted control angle. It can be easily illustrated by the following figure.



Relative position between back-emf and current – Illustration of control angle

The two previous figures show the parameters defining the line current (I peak, control angle, speed, conduction angle, rise and fall angle). The resulting line current is then applied in a transient simulation (with the Finite Element Analysis software – Flux®): the phase current, the phase voltage, Line-Line voltage, the electromagnetic torque, useful torque, and the losses are outputs of this transient simulation.
The other features described in the overview are the results of other internal post processing of FluxMotor®.

6.2.3 Computation of iron losses

When requested by the user, a specific computation can be performed to determine the amount of iron losses for the rotor and stator magnetic circuits.
To perform it, “Yes” must be answered for the input: “**Iron loss computation**”).

This computation is performed over half electrical period by using Finite Element modelling. The reconstituted signal is displayed by FluxMotor®.

The calculation of the iron losses based on the Steinmetz’s model, is carried out by using the Transient Magnetic application with a Finite Element Analysis – Flux®.

6.2.4 Computation of magnet losses

When requested by the user, a specific computation can be performed to determine the level of Joule losses inside the magnets.
To perform it, “Yes” must be answered for the input: “**Losses in magnets computation**”).

This computation is performed over half electrical period by using Finite Element modelling. The reconstituted signal is displayed by FluxMotor®.

FluxMotor® internal process considers the speed and the topology of the machine to get accurate results.
The calculation of the Joule losses is carried out by using the Transient Magnetic application with the Finite Element Analysis – Flux®.