

ALTAIR

Altair[®] FluxMotor[®] 2023

Induction machines – Squirrel cage - Inner rotor

Motor Factory – Test – Mechanics

General user information

Contents

1	<i>Mechanics – NVH – Working point – U - f - N</i>	5
1.1	Overview	5
1.1.1	Positioning and objective	5
1.1.2	User inputs	5
1.1.3	Main outputs	6
1.2	Settings	6
1.3	Inputs	7
1.3.1	Introduction	7
1.3.2	Standard inputs	7
1.3.2.1	Line-Line voltage, rms	7
1.3.2.2	Power supply frequency	7
1.3.2.3	Definition mode	7
1.3.2.4	Slip	7
1.3.2.5	Speed	7
1.3.3	Advanced input	8
1.3.3.1	Maximum engine order / No. Points per electrical period	8
1.3.3.2	Maximum mode / spatial order	8
1.3.3.3	Number of computations per tooth pitch	8
1.3.3.4	Displayed pressure range (dB)	8
1.3.3.5	Number of rotor turns	9
1.3.3.6	Computation of forces on teeth	9
1.3.3.7	Mesh order	9
1.3.3.8	Airgap mesh coefficient	9
1.4	Main principles of computation	10
1.4.1	Introduction	10
1.4.2	Flow chart	11
1.5	Test results	12
1.5.1	Introduction	12
1.5.2	List of the main NVH results	12
1.6	Limitation of computations - Advice for use	14
2	<i>Mechanics – NVH – Working point – I - f - N</i>	15
2.1	Overview	15
2.1.1	Positioning and objective	15
2.1.2	User inputs	16
2.1.3	Main outputs	16
2.2	Settings	16
2.3	Inputs	17
2.3.1	Introduction	17
2.3.2	Standard inputs	17
2.3.2.1	Line current, rms	17
2.3.2.2	Power supply frequency	17
2.3.2.3	Definition mode	17
2.3.2.4	Slip	17
2.3.2.5	Speed	17
2.3.3	Advanced input	18
2.3.3.1	Maximum engine order / No. Points per electrical period	18

2.3.3.2	Maximum mode / spatial order	18
2.3.3.3	Number of computations per tooth pitch	18
2.3.3.4	Displayed pressure range (dB)	18
2.3.3.5	Number of rotor turns	19
2.3.3.6	Computation of forces on teeth	19
2.3.3.7	Mesh order	19
2.3.3.8	Airgap mesh coefficient	19
2.4	Main principles of computation	20
2.5	Test results	20
2.6	Limitation of computations - Advice for use	20
3	<i>Mechanics – NVH – spectrogram – U - f - N</i>	21
3.1	Overview	21
3.1.1	Positioning and objective	21
3.1.2	User inputs	21
3.1.3	Main outputs	22
3.2	Settings	22
3.3	Inputs	23
3.3.1	Introduction	23
3.3.2	Standard inputs	23
3.3.2.1	U-f-N description	23
3.3.2.2	Definition mode	23
3.3.2.3	Slip	23
3.3.2.4	Speed	23
3.3.2.5	Process to define the list of working points	24
3.3.3	Advanced input	25
3.3.3.1	Maximum engine order / No. Points per electrical period	25
3.3.3.2	Maximum mode / spatial order	25
3.3.3.3	Number of computations per tooth pitch	25
3.3.3.4	Number of points for speed interpolation	25
3.3.3.5	Number of rotor turns	25
3.3.3.6	Mesh order	25
3.3.3.7	Airgap mesh coefficient	26
3.4	Main principles of computation	27
3.4.1	Introduction	27
3.4.2	Flow chart	28
3.5	Test results	29
3.5.1	Introduction	29
3.5.2	List of the main NVH results	29
3.6	Limitation of computations - Advice for use	30
4	<i>Mechanics – NVH – spectrogram – I - f - N</i>	31
4.1	Overview	31
4.1.1	Positioning and objective	31
4.1.2	User inputs	31
4.2	Settings	32
4.3	Inputs	33
4.3.1	Introduction	33
4.3.2	Standard inputs	33

4.3.2.1	I-f-N description	33
4.3.2.2	Definition mode	33
4.3.2.3	Slip	33
4.3.2.4	Speed	33
4.3.2.5	Process to define the list of working points	34
4.3.3	Advanced input	35
4.3.3.1	Maximum engine order / No. Points per electrical period	35
4.3.3.2	Maximum mode / spatial order	35
4.3.3.3	Number of computations per tooth pitch	35
4.3.3.4	Number of points for speed interpolation	35
4.3.3.5	Number of rotor turns	35
4.3.3.6	Mesh order	35
4.3.3.7	Airgap mesh coefficient	36
4.4	Main principles of computation	36
4.5	Test results	36
4.6	Limitation of computations - Advice for use	36

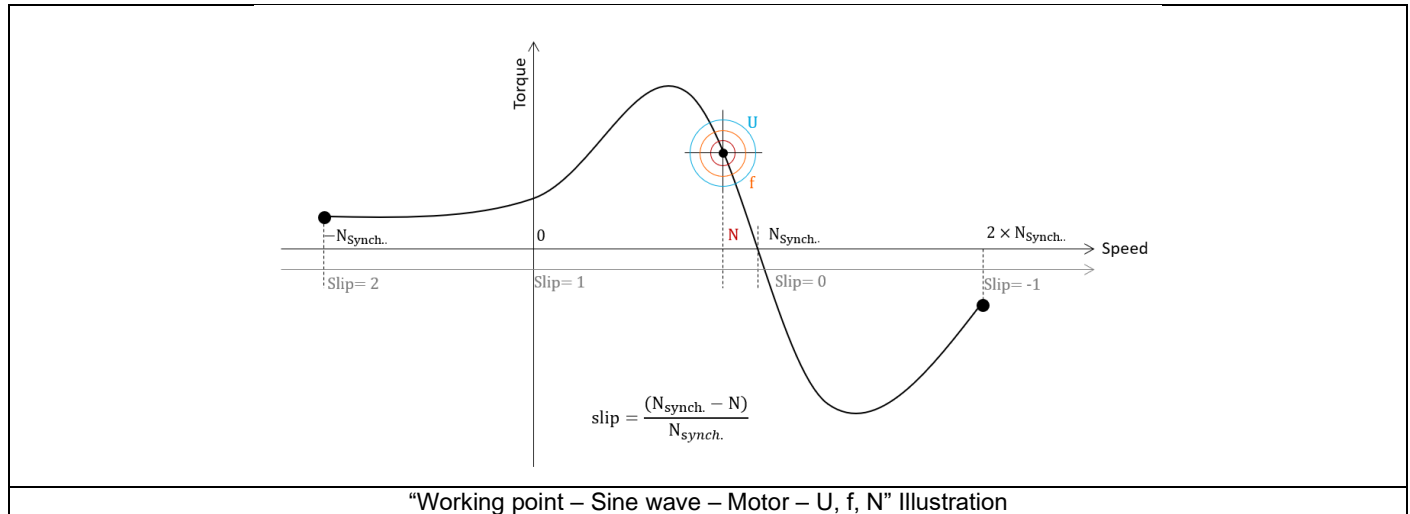
1 MECHANICS – NVH – WORKING POINT – U - F - N

1.1 Overview

1.1.1 Positioning and objective

The aim of the test “Mechanics – NVH – Working point – U-f-N” is to perform NVH analysis of the machine when operating at the targeted working point defined with the following inputs values U, f, N (Line-Line voltage, Power supply frequency, Speed).

This test is available only in the beta mode. It means that all the computation process and results are not entirely qualified yet. However, this gives users, the capability to use and to evaluate this new feature by themselves.



This test give data allowing NVH prediction in early electromagnetic and design stage.

The modal analysis of the stator mechanical structure, the sound power level and the magnetic forces applied on teeth are computed and displayed.

This test helps to answer the following question:

- Could the machine have any risks in connection with NVH? Yes / No.

The following table helps to classify the test “Mechanics – NVH – Working point – U-f-N”.

Family	Mechanics
Package	NVH
Convention	#
Test	Working point - U - f - N

Positioning of the test “Mechanics – NVH – Working point – U-f-N”.

1.1.2 User inputs

The three main user input parameters are the supplied Line-Line voltage, the power supply frequency, and the speed (or the slip). In addition, temperatures of winding and squirrel cage must be set.

1.1.3 Main outputs

Test results are illustrated with data, graph, and tables.

- 1) Tables of results
 - Machine performance - Working point defined with U-f-N
- 2) Graphs, curves, and maps to illustrate NVH analysis results
 - Modal analysis
 - Radiation efficiency
 - Space-Time normal flux density in the airgap
 - Space-Time Maxwell pressure
 - Sound power level
 - Electromagnetic forces on teeth

1.2 Settings

Two buttons give access to the following setting definition:

- Temperature of active components: winding and magnets
- Definition of mechanical loss model parameters

For more details, please refer to the document: [MotorFactory_2023_IMSQ_IOR_3PH_Test_Introduction](#).

1.3 Inputs

1.3.1 Introduction

The total number of inputs is equal to 11.
Among these inputs, 3 are standard inputs and 8 are advanced inputs.

1.3.2 Standard inputs

1.3.2.1 Line-Line voltage, rms

The rms value of the Line-Line voltage supplying the machine: "**Line-Line voltage, rms**" (*Line-Line voltage, rms value*) must be provided.
Note: The number of parallel paths and the winding connections are automatically considered in the results.

1.3.2.2 Power supply frequency

The value of the power supply frequency of the machine: "**Power supply frequency**" (*Power supply frequency*) must be provided.
The power supply frequency is the electrical frequency applied at the terminals of the machine.

1.3.2.3 Definition mode

There are 2 common ways to define the working point. It can be defined by indicating the slip "**Slip**" or by defining the operating speed of the machine "**Speed**".

1.3.2.4 Slip

When the choice of definition mode is "**Slip**", the value of machine's slip "**Slip**" (*Slip*) must be provided.
Note: The slip (s) corresponds to the difference between the speed of the rotating magnetic field in the stator (N_s = Synchronous speed) and the rotor operating speed (N).

$$s = \frac{N_s - N}{N_s}$$

Unit can be % or PU.

1.3.2.5 Speed

When the choice of definition mode is "**Speed**", the value of operating speed "**Speed**" (*Speed*) must be provided.

1.3.3 Advanced input

1.3.3.1 Maximum engine order / No. Points per electrical period

Two kinds of inputs are possible:

Define the **Max. engine order** (*Maximum engine order*) or the **No. points / elec. Period** (*Number of points per electric period*).

When decomposing the Maxwell pressure, applied on the stator, to get its harmonic contributions, the “**max. engine order**” (*Maximum engine order*) is required to compute its decomposition in function of the time.

At a practical point of view, when the maximum engine order is equal to N, that leads to consider 2*N computation points over a complete rotation period of the rotor.

Note 1: The input "Engine order" is in connection with the frequency of vibration.

"Engine order" refers to a mechanical revolution period of the motor whereas frequency refers to the considered electrical period.

Obviously, both are linked with speed.

For instance, sound power level can be displayed either by considering frequency or engine order.

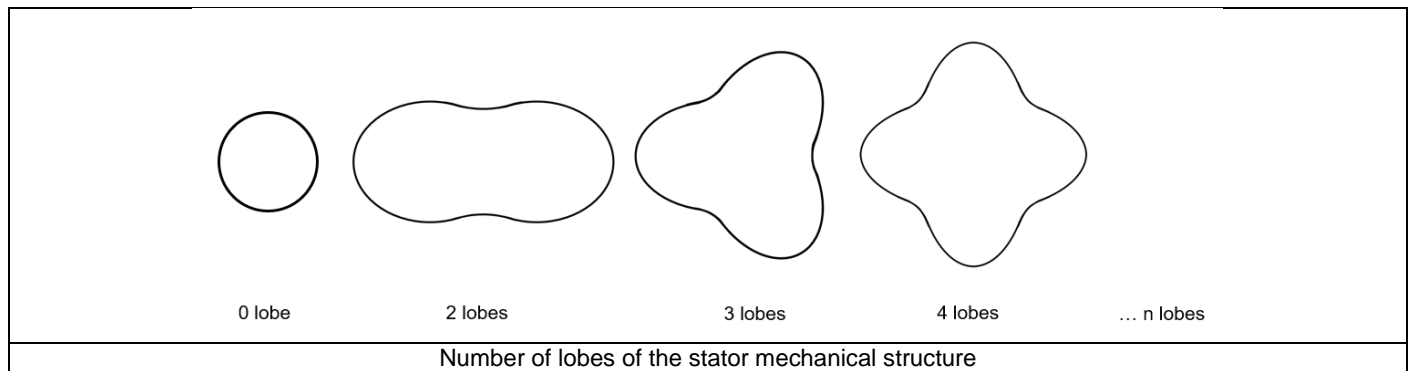
Note 2: There are two possibilities, either set an engine order or a number of points per electrical period.

For transient computations the minimum needed number of points per electrical period is 40.

So, when the engine order is not high enough to reach this constraint, it is automatically modified to get 40 computation points per electrical period.

1.3.3.2 Maximum mode / spatial order

The “**max. mode / spatial order**” (*Maximum mode / spatial order*) input allows the user to define the number of modes to be considered for the acoustic structural analysis. If the user selects 25, it means that the highest number of lobes in the stator deformation will be equal to 25 lobes. All deformations corresponding to more than 25 lobes will be dismissed.



1.3.3.3 Number of computations per tooth pitch

The “**No. comp./tooth pitch**” (*Number of computations per tooth pitch*) allows to choose the number of Maxwell pressure evaluations per tooth. The more points selected, the more accurate the Maxwell pressure harmonic decomposition will be.

1.3.3.4 Displayed pressure range (dB)

The “**displayed pressure range (dB)**” (*Displayed Maxwell pressure range*) is only related to the displaying of results.

It allows to increase/decrease the range of non-zero contributions displayed in the Maxwell pressure harmonic decomposition map.

When one chooses a displayed pressure range equal to 50 dB, only the contributions within the range of 50 dB and below the maximum computed value is displayed.

Note that the absolute reference value P_{ref} (expressed in Pa), which corresponds to 0 dB, is indicated in the working point table.

Considering this referent value P_{ref} , one can compute any Maxwell pressure value P_{Pa} (expressed in Pa) from the ones expressed in Decibel P_{dB} .

The relations between these quantities are illustrated below:

$$P_{dB} = 20 \times \text{Log}_{10} \left(\frac{P_{Pa}}{P_{ref}} \right) \quad P_{Pa} = P_{ref} \times 10^{\frac{P_{dB}}{20}}$$

The default value is equal to 60. The range of possible values is [20;100].

1.3.3.5 Number of rotor turns

This input allows us to define the number of rotor revolutions to consider the slip as far as possible. Higher is the number of rotor revolutions better will be the results. However, this value has a huge impact on the computation time. The default value is equal to 5. This is a good compromise between computation time and quality of results. The variation range of values for this parameter is [1; 10].

1.3.3.6 Computation of forces on teeth

The “**computation of forces on teeth**” (*Additional analysis to compute the force on teeth*) allows to perform or not, the additional analysis which is the computation of force on teeth. Since this computation requires bigger memory and an additional computation time, this input allows to consider it as an additional option.

1.3.3.7 Mesh order

To get the results, the original computation is performed using a Finite Element Modeling. Two levels of meshing can be considered for this finite element calculation: first order and second order. This parameter influences the accuracy of results and the computation time.

By default, second order mesh is used.

1.3.3.8 Airgap mesh coefficient

The advanced user input “**Airgap mesh coefficient**” is a coefficient which adjusts the size of mesh elements inside the airgap. When the value of “**Airgap mesh coefficient**” decreases, the mesh elements get smaller, leading to a higher mesh density inside the airgap, increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux® software, is described as:

$$\text{MeshPoint} = (\text{airgap}) \times (\text{airgap mesh coefficient})$$

Airgap mesh coefficient is set to 1.5 by default. The variation range of values for this parameter is [0.05; 2]. 0.05 giving a very high mesh density and 2 giving a very coarse mesh density.

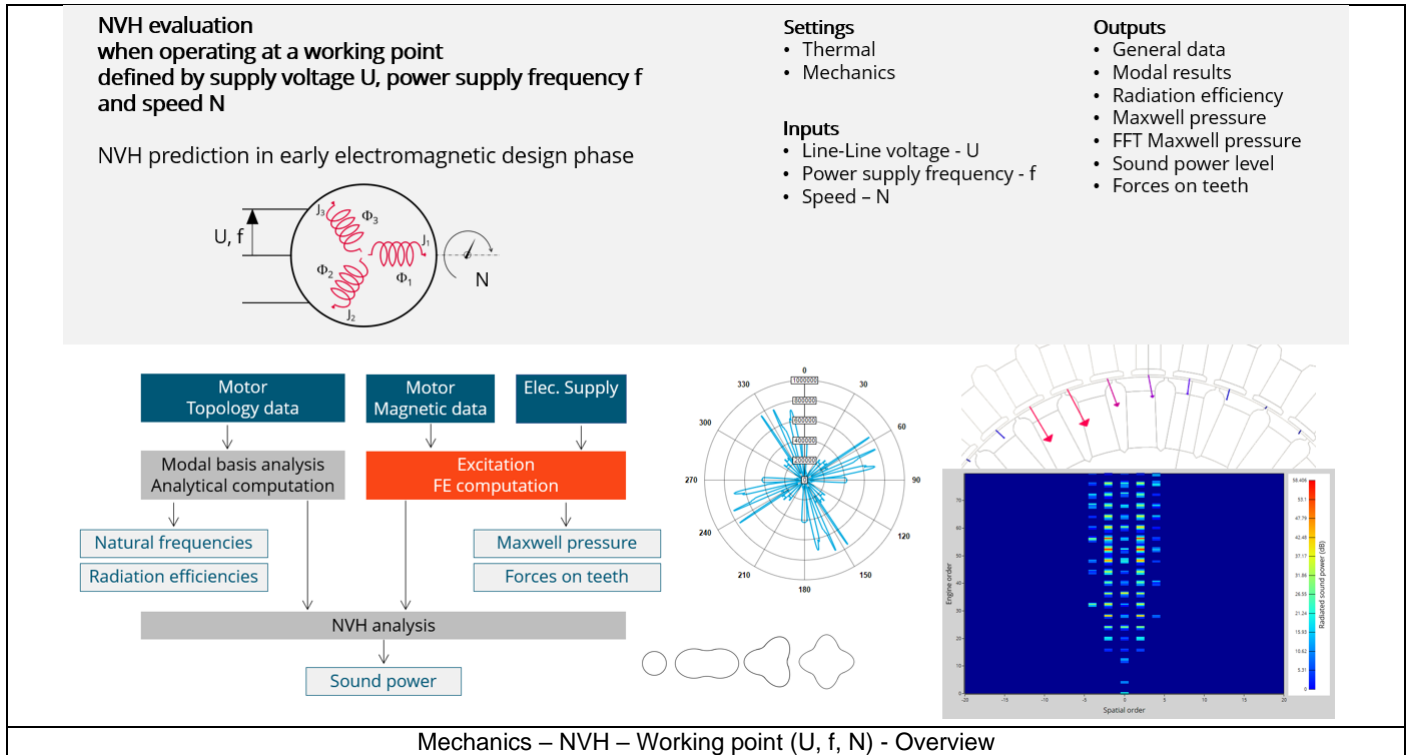
Caution:

Be aware, a very high mesh density does not always mean a better result quality. However, this always leads to a huge number of nodes in the corresponding finite element model. So, it means a need of huge numerical memory and increases the computation time considerably.

1.4 Main principles of computation

1.4.1 Introduction

Here are illustrations which give an overview of the test NVH – Working point (U,f,N):



DESIGN

TEST

EXPORT

CHARACTERIZATION

WORKING POINT

PERFORMANCE MAPPING

MECHANICS

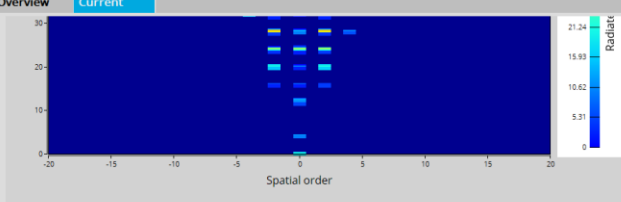
?

SECTIONS

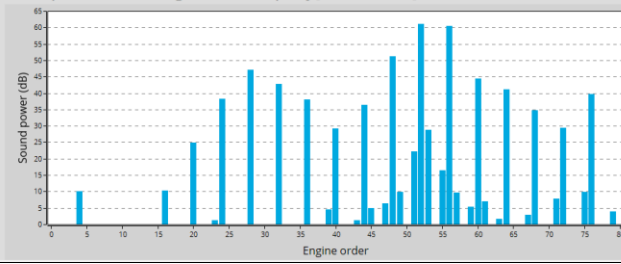
- Inputs
- Settings
- Winding & Cage
- Emag. results
- Working point
- NVH results
 - Modal analysis
 - Radiation efficiency
 - B airgap
 - Maxwell pressure
 - Maxwell pressure
 - Maxwell pressure
 - Sound power
 - Sound power
 - Forces

MECHANICS - NVH - WORKING POINT - VOLTAGE-FREQUENCY-SPEED (BETA VERSION)

Overview **Current**



Sound power level versus engine order or frequency [dB ref. = 1E-12W]



NVH

Working Point

Spectrogram

U-f-N (III) I-f-N (III)

Thermal Mechanics

INPUTS

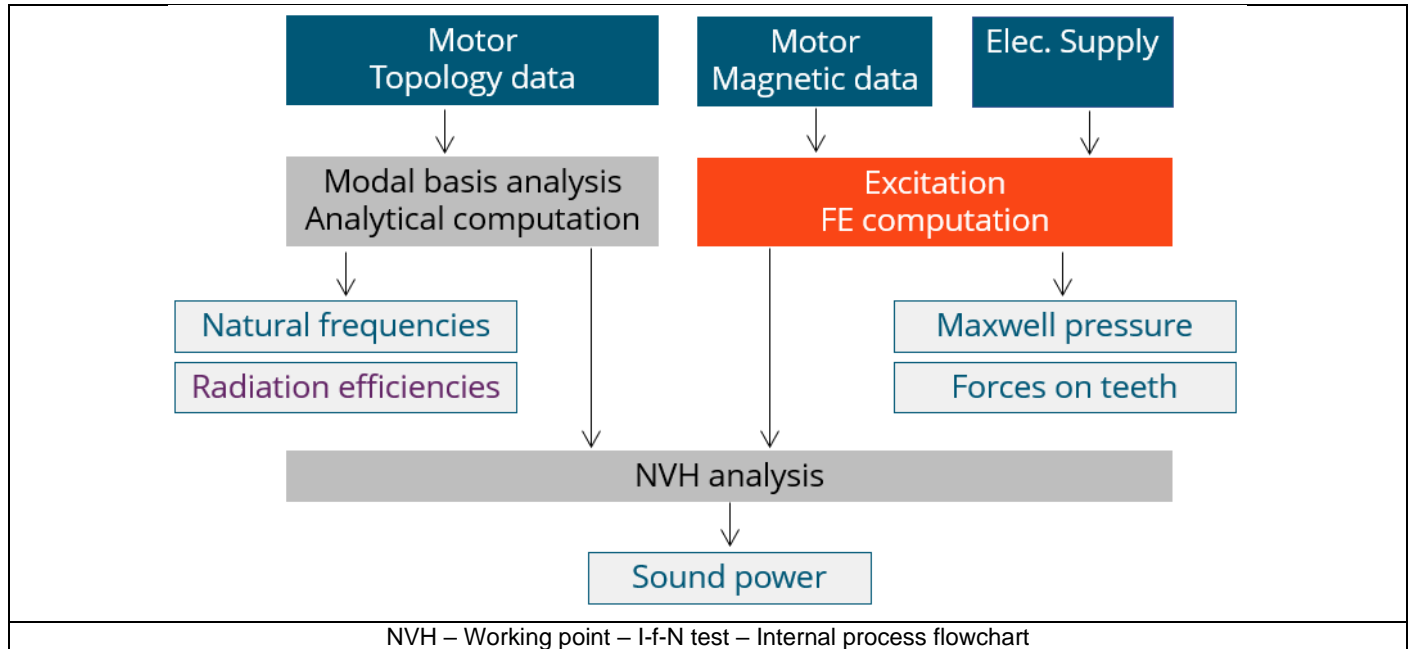
Line-Line voltage rms (V)	78.0
Power supply frequency (Hz)	75.0
Speed (rpm)	2 187.0

Play, Refresh, Save icons

Mechanics – NVH – Working point (U, f, N) - Test results

1.4.2 Flow chart

Here is the flowchart illustrating the internal process of the thermal test.



The inputs of the internal process are the parameters of:

- Motor topology data
- Motor magnetic data
- Electrical supply

The resulting NVH evaluation is based, first, on analytical computations allowing to characterize the modal analysis of the machine stator. Then, a time-space harmonic analysis of the Maxwell pressure computed in the airgap is performed. The Maxwell pressure is obtained from the normal flux density in the airgap computed in a 2D finite elements transient analysis.

Once this harmonic decomposition of the Maxwell pressure is performed, it is combined with the modal analysis of the machine to extract the acoustic power.

1.5 Test results

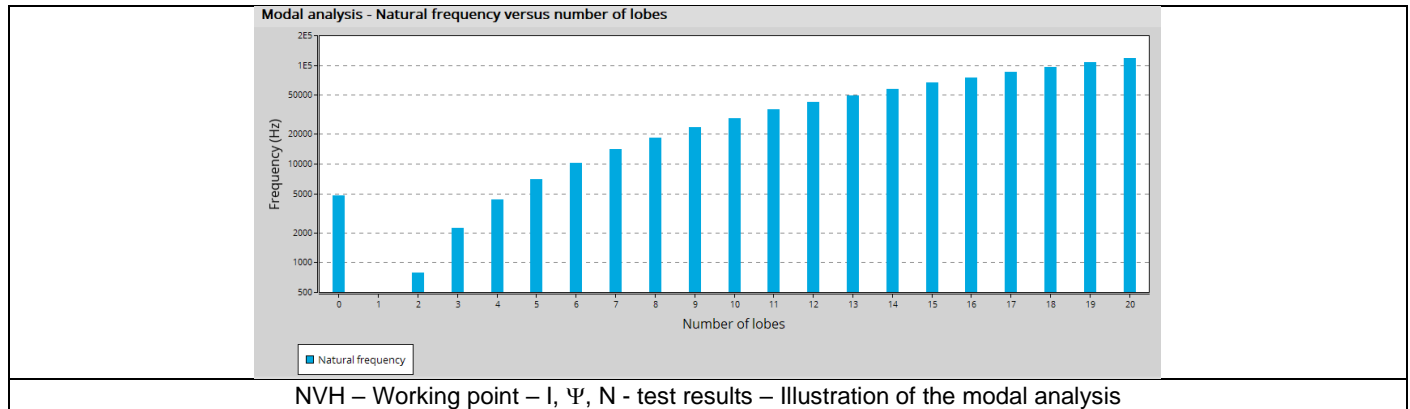
1.5.1 Introduction

Before analyzing the test results, take care of advices for use reminded in the section 1.6 (Limitation of computations - Advice for use)

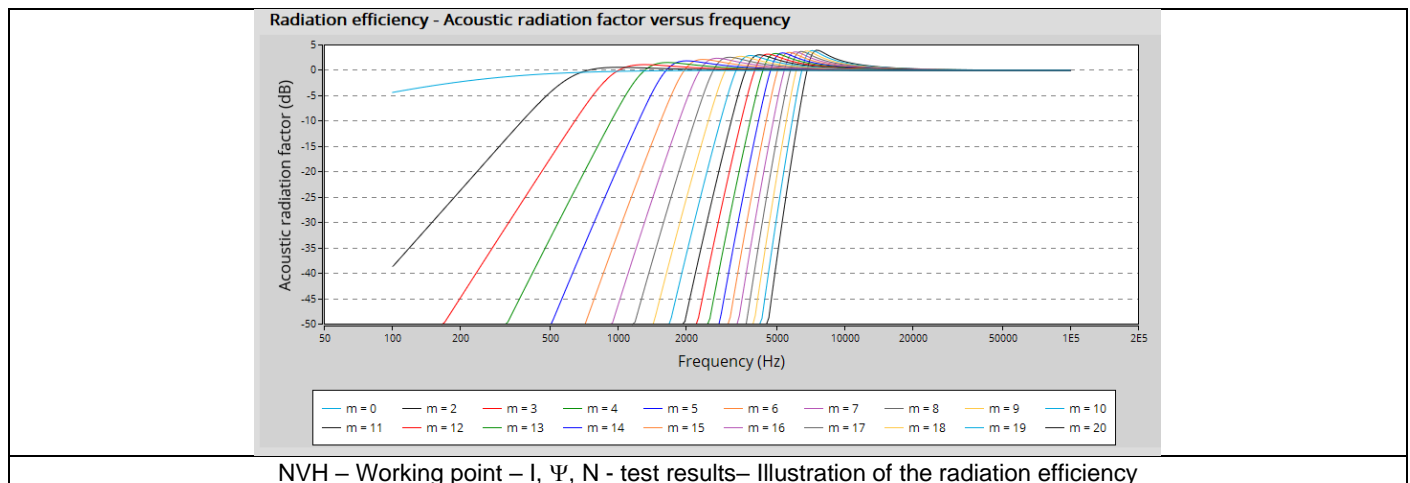
Electromagnetic results are computed and displayed to illustrate the considered working point at an electromagnetic point of view. The general data illustrate the machine performance. Information about NVH are listed like overall sound power. The magnitudes of forces on teeth (mean and maximum values) are displayed.

1.5.2 List of the main NVH results

- 1) Modal analysis – Natural frequency versus number of lobes: This graph displays the natural frequency corresponding to the n-lobe deformation.

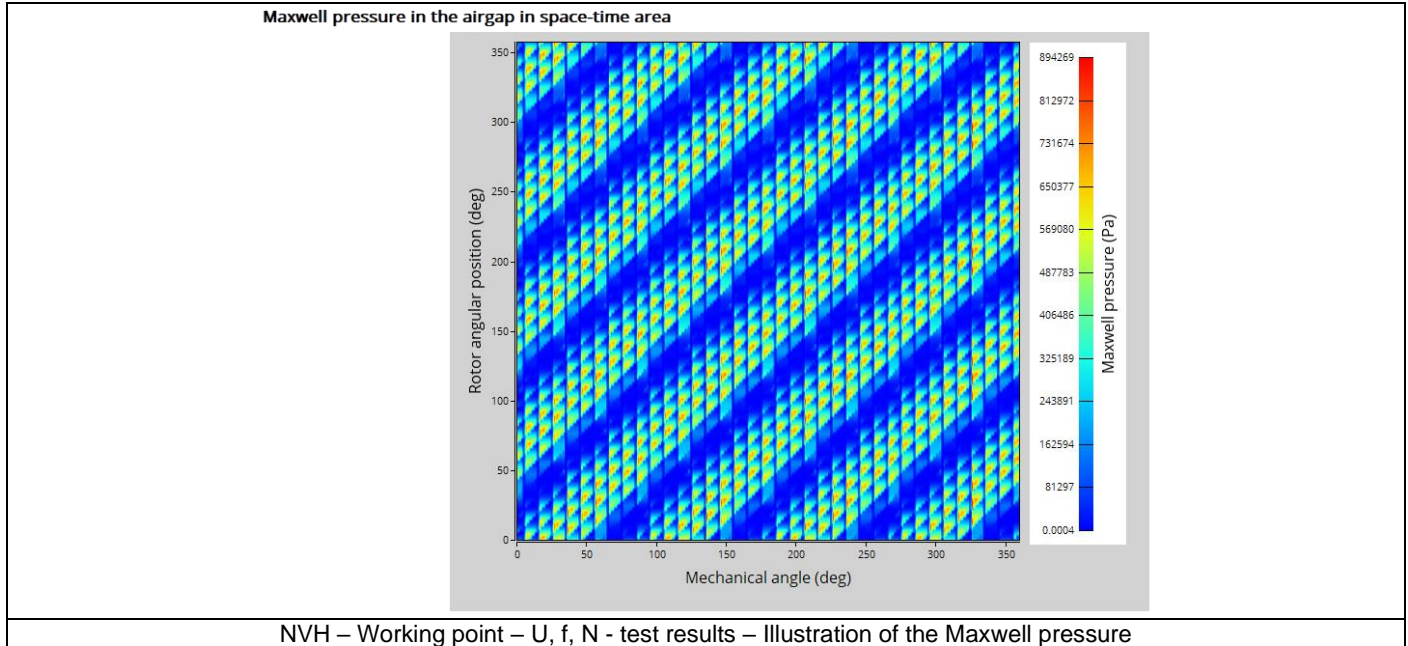


- 2) Radiation efficiency – Acoustic radiation factor versus frequency: This graph illustrates the capacity of the stator to convert vibration into noise.

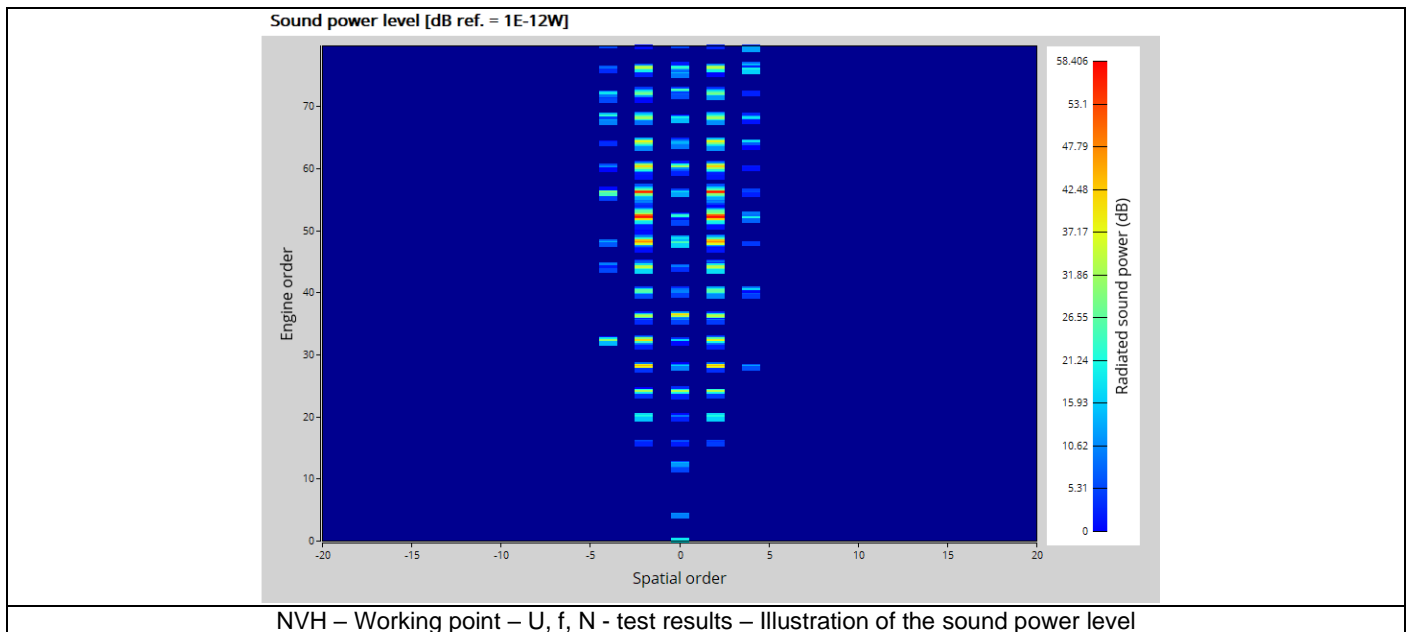


- 3) Normal flux density in the airgap in space-time area: This map is a time-space description of the flux density in the airgap.

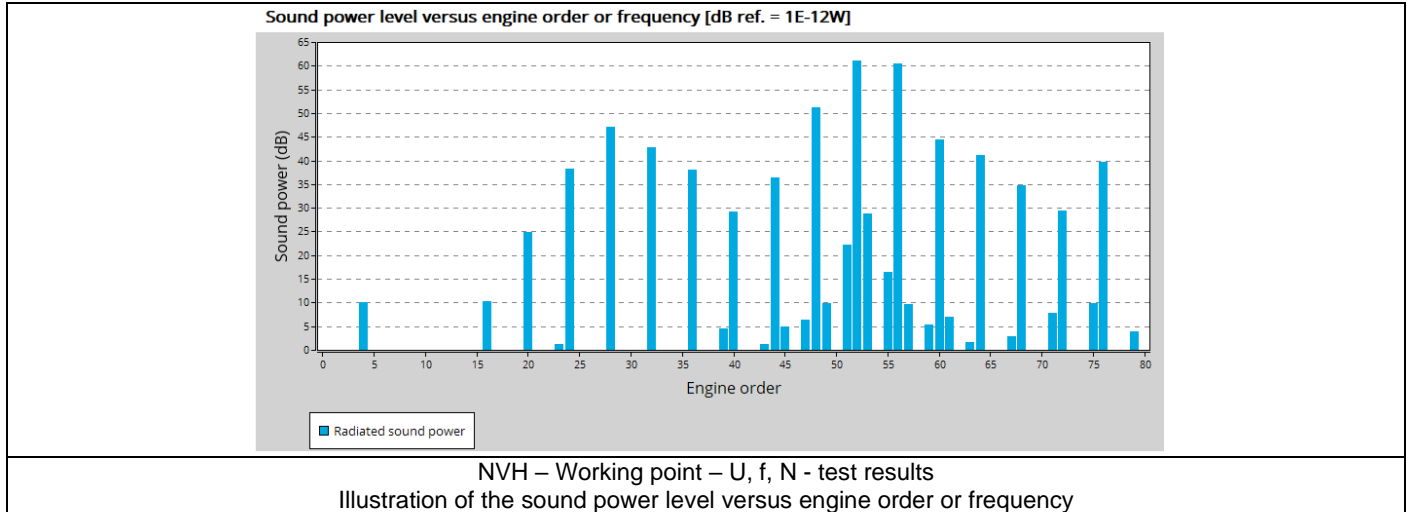
- 4) Maxwell pressure in the airgap in space-time area: This map is a time-space description of the normal Maxwell pressure in the airgap.



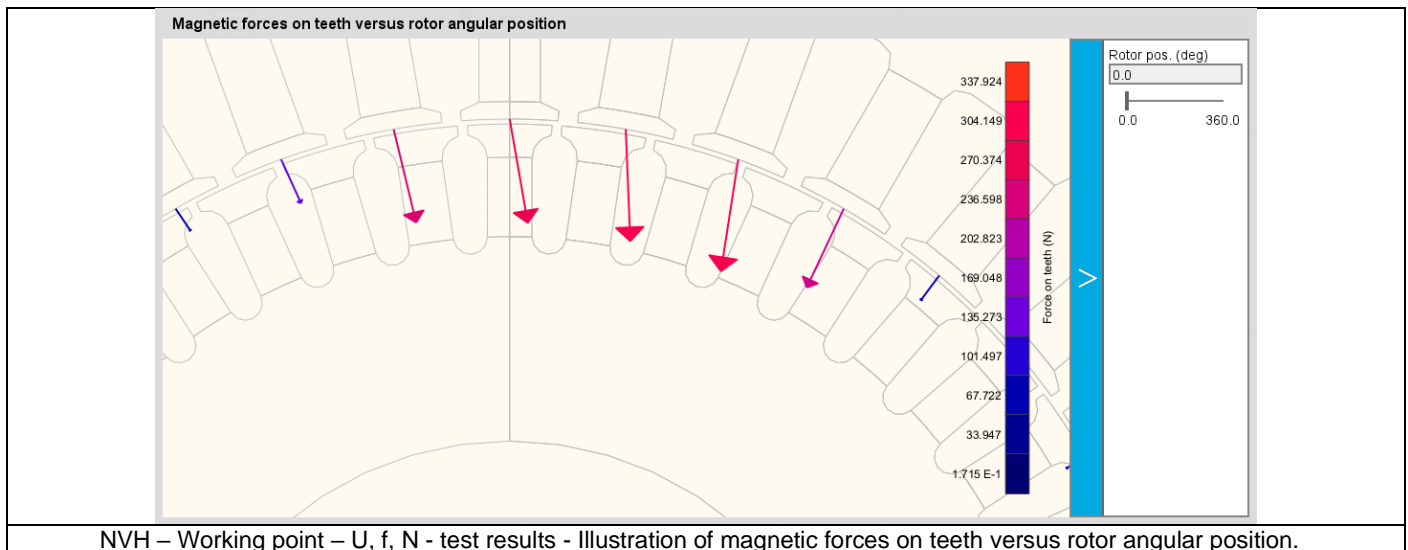
- 5) Maxwell pressure in the airgap versus rotor angular position: This curve displays the normal Maxwell pressure in the airgap for a given angular position of the rotor
- 6) Maxwell pressure space-time harmonic analysis: This map displays the magnitude of the harmonic decomposition for the magnetic excitation.
- 7) Sound power level with 0dB corresponding to E-12 W: This map displays the harmonic decomposition of the sound power level.



- 8) Sound power level versus engine order or frequency with 0dB c corresponding to $E^{-12} W$: This histogram shows the sound power level per engine order (or frequency) with a $1E^{-12}W$ as reference



- 9) Magnetic forces on teeth or rotor versus rotor angular position.



1.6 Limitation of computations - Advice for use

The modal analysis as well as the radiation efficiency are based on an analytical computation where the stator of the machine is considered as a vibrating cylinder.

The considered cylinder behavior is weighted by the additional masses like the fins or the winding and the subtractive masses like the slots and the cooling circuit holes.

This assumption allows to get fast evaluation of the behavior of machine in connection to NVH. In no way this can replace a mechanical Finite Element modeling and simulation.

Among possible reasons for deviations of results can be the following ones:

- The limits of the analytical model are reached or overpassed
- Unusual topology and/or dimensions of the teeth/slots
- Complexity of the stator-frame structure when it is composed with several components for instance
- The ratio between the total length of the frame L_{frame} and the stack length of the machine L_{stk} in any case, this ratio must be lower than 1.5:

$$\frac{L_{Frame}}{L_{stk}} \leq 1.5$$

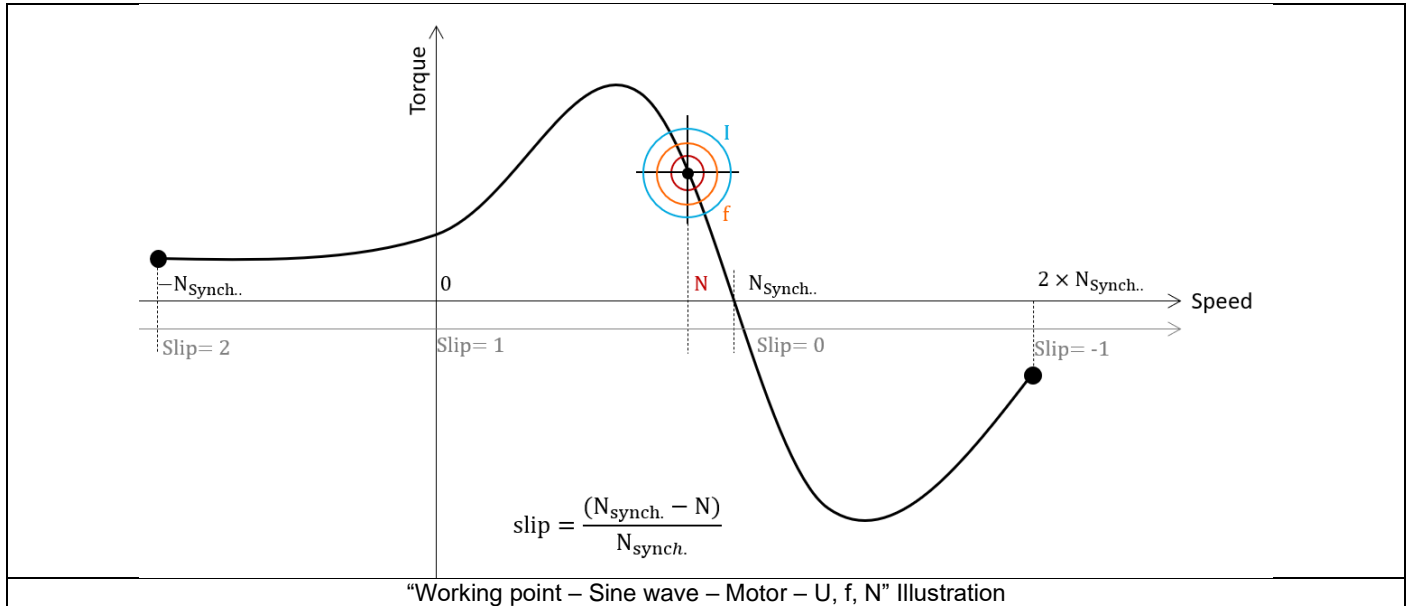
2 MECHANICS – NVH – WORKING POINT – I - F - N

2.1 Overview

2.1.1 Positioning and objective

The aim of the test “Mechanics – NVH – Working point – I-f-N” is to perform NVH analysis of the machine when operating at the targeted working point defined with the following inputs values I, f, N (Line current, Power supply frequency, Speed).

This test is available only in the beta mode. It means that all the computation process and results are not entirely qualified yet. However, this gives users, the capability to use and to evaluate this new feature by themselves.



This test give data allowing NVH prediction in early electromagnetic and design stage.

The modal analysis of the stator mechanical structure, the sound power level and the magnetic forces applied on teeth are computed and displayed.

This test helps to answer the following question:

- Could the machine have any risks in connection with NVH? Yes / No.

The following table helps to classify the test “Mechanics – NVH – Working point – U-f-N”.

Family	Mechanics
Package	NVH
Convention	#
Test	Working point - I - f - N

Positioning of the test “Mechanics – NVH – Working point – I-f-N”.

2.1.2 User inputs

The three main user input parameters are the Line current, the power supply frequency and the speed. In addition, temperatures of winding and squirrel cage must be set.

2.1.3 Main outputs

Test results are illustrated with data, graph, and tables. Please, refer to the test “Mechanics – NVH – Working point – U-f-N” to get information.

2.2 Settings

Two buttons give access to the following setting definition:

- Temperature of active components: winding and squirrel cage
- Definition of mechanical loss model parameters

For more details, please refer to the document: [MotorFactory_2023_IMSQ_IOR_3PH_Test_Introduction](#).

2.3 Inputs

2.3.1 Introduction

The total number of inputs is equal to 11.
Among these inputs, 3 are standard inputs and 8 are advanced inputs.

2.3.2 Standard inputs

2.3.2.1 Line current, rms

The rms value of the Line current supplying the machine: “**Line current, rms**” (*Line current, rms value*) must be provided.
Note: The number of parallel paths and the winding connections are automatically considered in the results.

2.3.2.2 Power supply frequency

The value of the power supply frequency of the machine: “**Power supply frequency**” (*Power supply frequency*) must be provided.
The power supply frequency is the electrical frequency applied at the terminals of the machine.

2.3.2.3 Definition mode

There are 2 common ways to define the working point. It can be defined by indicating the slip “**Slip**” or by defining the operating speed of the machine “**Speed**”.

2.3.2.4 Slip

When the choice of definition mode is “**Slip**”, the value of machine’s slip “**Slip**” (*Slip*) must be provided.
Note: The slip (*s*) corresponds to the difference between the speed of the rotating magnetic field in the stator (N_s = Synchronous speed) and the rotor operating speed (*N*).

$$s = \frac{N_s - N}{N_s}$$

Unit can be % or PU.

2.3.2.5 Speed

When the choice of definition mode is “**Speed**”, the value of operating speed “**Speed**” (*Speed*) must be provided.

2.3.3 Advanced input

2.3.3.1 Maximum engine order / No. Points per electrical period

Two kinds of inputs are possible:

Define the **Max. engine order** (*Maximum engine order*) or the **No. points / elec. Period** (*Number of points per electric period*).

When decomposing the Maxwell pressure, applied on the stator, to get its harmonic contributions, the “**max. engine order**” (*Maximum engine order*) is required to compute its decomposition in function of the time.

At a practical point of view, when the maximum engine order is equal to N, that leads to consider 2*N computation points over a complete rotation period of the rotor.

Note 1: The input "Engine order" is in connection with the frequency of vibration.

"Engine order" refers to a mechanical revolution period of the motor whereas frequency refers to the considered electrical period.

Obviously, both are linked with speed.

For instance, the sound power level can be displayed either by considering frequency or engine order.

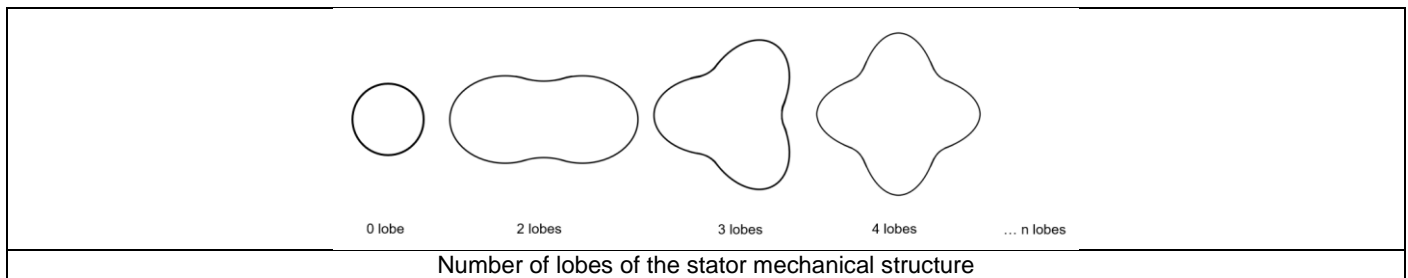
Note 2: There are two possibilities, either set an engine order or a number of points per electrical period.

For transient computations the minimum needed number of points per electrical period is 40.

So, when the engine order is not high enough to reach this constraint It is automatically modified to get 40 computation points per electrical period.

2.3.3.2 Maximum mode / spatial order

The “**max. mode / spatial order**” (*Maximum mode / spatial order*) input allows the user to define the number of modes to be considered for the acoustic structural analysis. If the user selects 25, it means that the highest number of lobes in the stator deformation will be equal to 25 lobes. All deformations corresponding to more than 25 lobes will be dismissed.



2.3.3.3 Number of computations per tooth pitch

The “**No. comp./tooth pitch**” (*Number of computations per tooth pitch*) allows to choose the number of Maxwell pressure evaluations per tooth. The more points selected, the more accurate the Maxwell pressure harmonic decomposition will be.

2.3.3.4 Displayed pressure range (dB)

The “**displayed pressure range (dB)**” (*Displayed Maxwell pressure range*) is only related to the displaying of results.

It allows to increase/decrease the range of non-zero contributions displayed in the Maxwell pressure harmonic decomposition map.

When one chooses a displayed pressure range equal to 50 dB, only the contributions within the range of 50 dB and below the maximum computed value is displayed.

Note that the absolute reference value P_{ref} (expressed in Pa), which corresponds to 0 dB, is indicated in the working point table.

Considering this referent value P_{ref} , one can compute any Maxwell pressure value P_{Pa} (expressed in Pa) from the ones expressed in Decibel P_{dB} .

The relations between these quantities are illustrated below:

$$P_{dB} = 20 \times \text{Log}_{10} \left(\frac{P_{Pa}}{P_{ref}} \right) \quad P_{Pa} = P_{ref} \times 10^{\frac{P_{dB}}{20}}$$

The default value is equal to 60. The range of possible values is [20;100].

2.3.3.5 Number of rotor turns

This input allows us to define the number of rotor revolutions to consider the slip as far as possible. Higher is the number of rotor revolutions better will be the results. However, this value has a huge impact on the computation time. The default value is equal to 5. This is a good compromise between computation time and quality of results. The variation range of values for this parameter is [1; 10].

2.3.3.6 Computation of forces on teeth

The “**computation of forces on teeth**” (*Additional analysis to compute the force on teeth*) allows to perform or not, the additional analysis which is the computation of force on teeth. Since this computation requires bigger memory and an additional computation time, this input allows to consider it as an additional option.

2.3.3.7 Mesh order

To get the results, the original computation is performed using a Finite Element Modeling. Two levels of meshing can be considered for this finite element calculation: first order and second order. This parameter influences the accuracy of results and the computation time.

By default, second order mesh is used.

2.3.3.8 Airgap mesh coefficient

The advanced user input “**Airgap mesh coefficient**” is a coefficient which adjusts the size of mesh elements inside the airgap. When the value of “**Airgap mesh coefficient**” decreases, the mesh elements get smaller, leading to a higher mesh density inside the airgap, increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux® software, is described as:

$$\text{MeshPoint} = (\text{airgap}) \times (\text{airgap mesh coefficient})$$

Airgap mesh coefficient is set to 1.5 by default. The variation range of values for this parameter is [0.05; 2]. 0.05 giving a very high mesh density and 2 giving a very coarse mesh density.

Caution:

Be aware, a very high mesh density does not always mean a better result quality. However, this always leads to a huge number of nodes in the corresponding finite element model. So, it means a need of huge numerical memory and increases the computation time considerably.

2.4 Main principles of computation

Same principles of computation than in the test “Mechanics – NVH – Working point – U-f-N”.

2.5 Test results

Same results than in the test “Mechanics – NVH – Working point – U-f-N”

2.6 Limitation of computations - Advice for use

The modal analysis as well as the radiation efficiency are based on an analytical computation where the stator of the machine is considered as a vibrating cylinder.

The considered cylinder behavior is weighted by the additional masses like the fins or the winding and the subtractive masses like the slots and the cooling circuit holes.

This assumption allows to get fast evaluation of the behavior of machine in connection to NVH. In no way this can replace a mechanical Finite Element modeling and simulation.

Among possible reasons for deviations of results can be the following ones:

- The limits of the analytical model are reached or overpassed
- Unusual topology and/or dimensions of the teeth/slots
- Complexity of the stator-frame structure when it is composed with several components for instance
- The ratio between the total length of the frame L_{frame} and the stack length of the machine L_{stk} in any case, this ratio must be lower than 1.5:

$$\frac{L_{Frame}}{L_{stk}} \leq 1.5$$

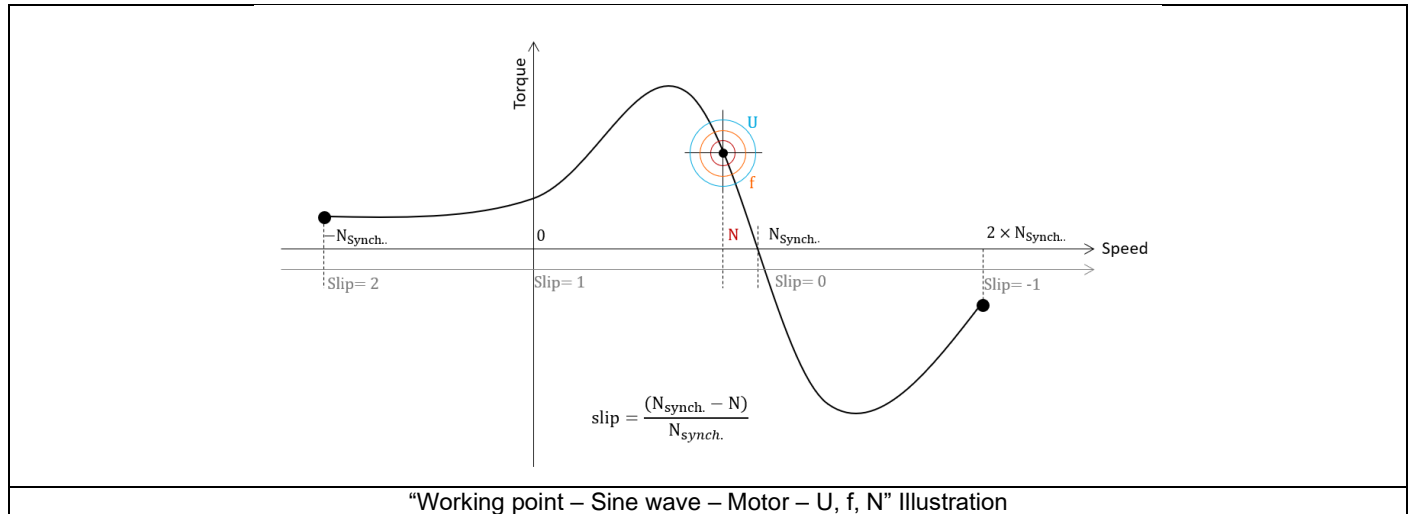
3 MECHANICS – NVH – SPECTROGRAM – U - F - N

3.1 Overview

3.1.1 Positioning and objective

The aim of the test “Mechanics – NVH – Spectrogram – U-f-N” is to perform NVH analysis on the machine when operating at a set of targeted working points defined with the following inputs values U, f, N (Line-Line voltage, Power supply frequency, Speed).

This test is available only in the beta mode. It means that all the computation process and results are not entirely qualified yet. However, this gives users, the capability to use and to evaluate this new feature by themselves.



This test give data allowing NVH prediction in early electromagnetic and design stage.

The modal analysis of the stator mechanical structure, the sound power level spectrogram per engine order versus speed and the resulting overall weighted sound power level versus speed are computed and displayed.

These results allow to see if there are any problems linked with NVH over the considered speed range.

And finally, this test helps to answer the following question:

- Could the machine have any risks in connection with NVH? Yes / No.

The following table helps to classify the test “Mechanics – NVH – Spectrogram – U-f-N”.

Family	Mechanics
Package	NVH
Convention	#
Test	Spectrogram - U - f - N

Positioning of the test “Mechanics – NVH – Spectrogram – U-f-N”

3.1.2 User inputs

The three main user input parameters are the supplied Line-Line voltage, the power supply frequency, and the speed (or the slip). In addition, temperatures of winding and squirrel cage must be set.

3.1.3 Main outputs

Test results are illustrated with data, graphs, and tables.

- 1) Curves to give an overview of the electromagnetic behavior of the machine versus speed
 - Power
 - Mechanical torque
 - Line current
 - Control angle
 - Magnet temperature

- 2) Graphs, curves, and maps to illustrate NVH analysis results
 - Modal analysis
 - Radiation efficiency
 - Sound power level spectrogram in speed-engine order area
 - Sound power level spectrogram in speed-frequency area
 - Overall weighted sound power level versus speed

3.2 Settings

Two buttons give access to the following setting definition:

- Temperature of active components: winding and magnets
- Definition of mechanical loss model parameters

For more details, please refer to the document: [MotorFactory_2023_IMSQ_IOR_3PH_Test_Introduction](#).

3.3 Inputs

3.3.1 Introduction

The total number of inputs is equal to 7.

Among these inputs, 1 is a standard input and 6 are advanced inputs.

Note that the standard input corresponds to a table to be filled with a set of working point described as indicated in the following section.

3.3.2 Standard inputs

3.3.2.1 U-f-N description

The “**U-f-N description**” allows to define several working points.

The description must be defined by clicking on the button “Set values”.

Then, two ways are possible to fill in the table: either filling the table line per line or by importing an Excel file in which all the working points to be considered are defined.

Note 1: There must be at least two working points.

Note 2: The speed column must contain increasing speeds.

Each working point is described by the following data:

1) Line current, rms

The rms value of the line current supplying the machine: “**Line current, rms**” (*Line current, rms value*) must be provided.

Note: The number of parallel paths and the winding connections are automatically considered in the results.

2) Power supply frequency

The value of the power supply frequency of the machine: “**Power supply frequency**” (*Power supply frequency*) must be provided.

The power supply frequency is the electrical frequency applied at the terminals of the machine.

3.3.2.2 Definition mode

There are 2 common ways to define the working point. It can be defined by indicating the slip “**Slip**” or by defining the operating speed of the machine “**Speed**”.

3.3.2.3 Slip

When the choice of definition mode is “**Slip**”, the value of machine’s slip “**Slip**” (*Slip*) must be provided.

Note: The slip (s) corresponds to the difference between the speed of the rotating magnetic field in the stator (N_s = Synchronous speed) and the rotor operating speed (N).

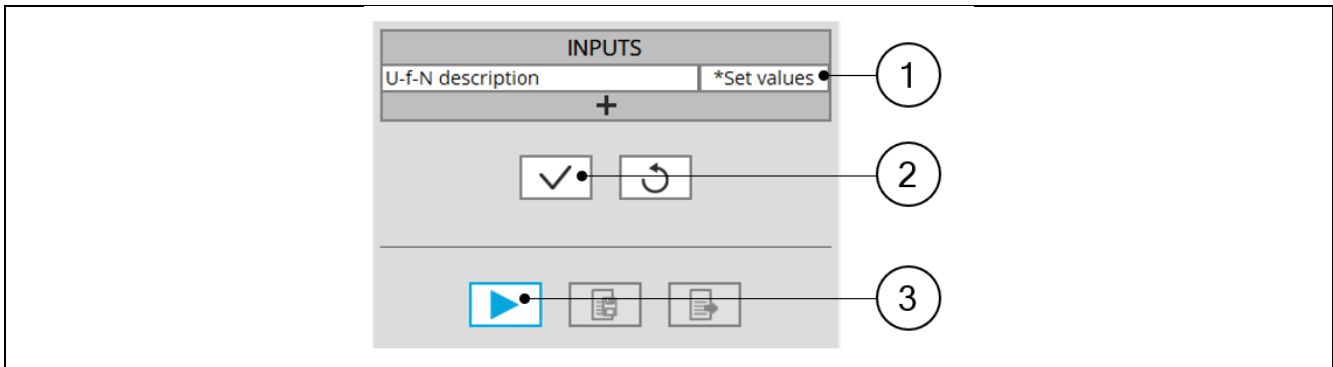
$$s = \frac{N_s - N}{N_s}$$

Unit can be % or PU.

3.3.2.4 Speed

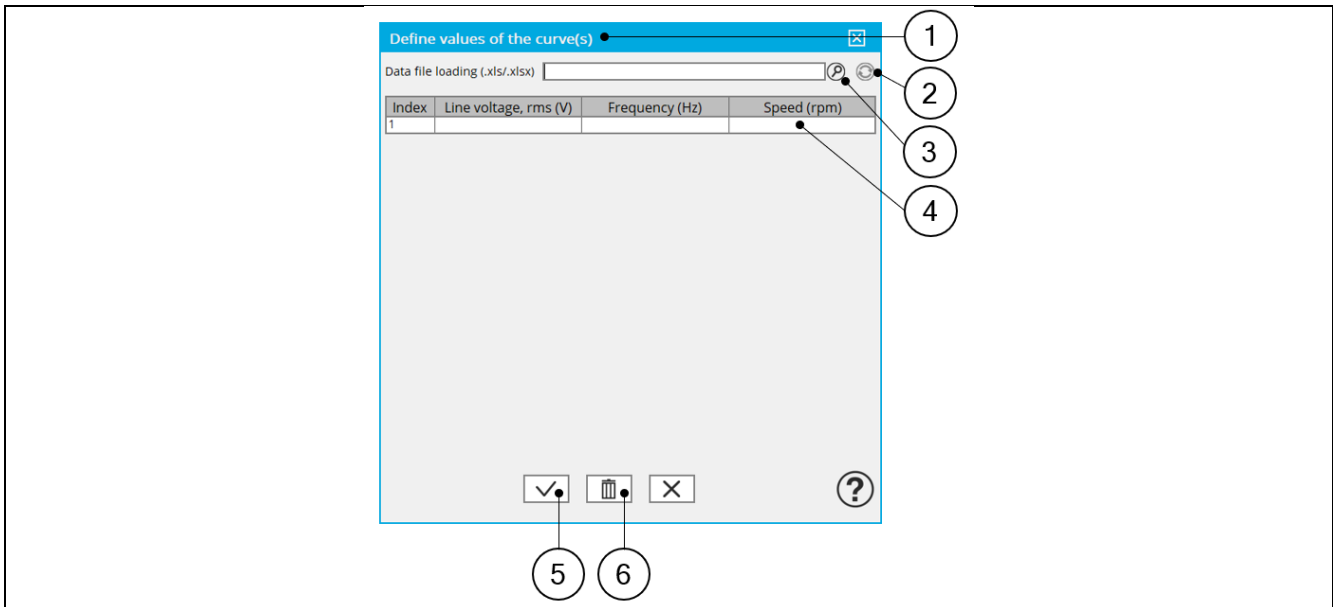
When the choice of definition mode is “**Speed**”, the value of operating speed “**Speed**” (*Speed*) must be provided.

3.3.2.5 Process to define the list of working points



List of working points to be defined

1	Click on the button "Set values" of the field " U, f, N description" to define the working points in a dialog box. Refer to the next illustration which shows how to fill the working point table.
2	Button to validate the user input data
3	Button to run the computations



Dialog box to define the list of working points

1	Dialog box opened after having clicked on the button "Set values" in the field "Cycle description"
2	Browse the folder to select an Excel file to define the working points to be considered
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the list of working points to be considered

U-f-N input			
Label	voltage	frequency	Speed
Units	V	Hz	rpm
Values	100	50	1000
	120	200	5000
	135	400	9000

Excel file template to define the list of working points

3.3.3 Advanced input

3.3.3.1 Maximum engine order / No. Points per electrical period

Two kinds of inputs are possible:

Define the **Max. engine order** (*Maximum engine order*) or the **No. points / elec. Period** (*Number of points per electric period*).

When decomposing the Maxwell pressure, applied on the stator, to get its harmonic contributions, the “**max. engine order**” (*Maximum engine order*) is required to compute its decomposition in function of the time.

At a practical point of view, when the maximum engine order is equal to N, that leads to consider $2*N$ computation points over a complete rotation period of the rotor.

Note 1: The input "Engine order" is in connection with the frequency of vibration.

"Engine order" refers to a mechanical revolution period of the motor when frequency refers to the considered electrical period.

Obviously, both are linked with speed.

For instance, sound power level can be displayed either by considering frequency or engine order.

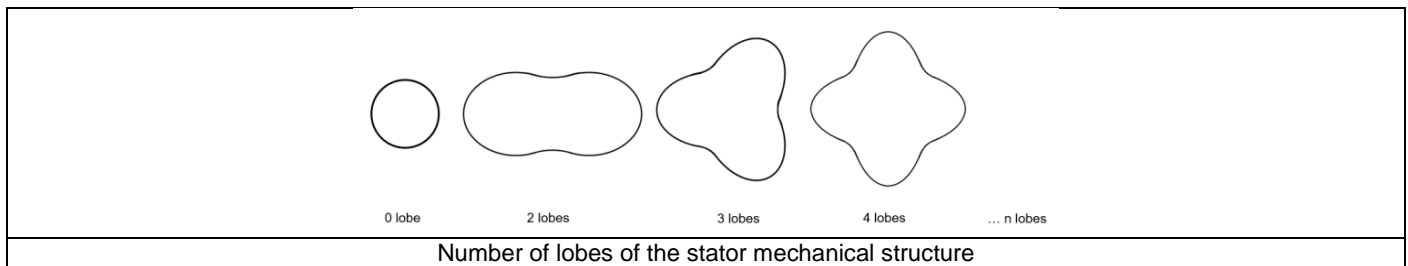
Note 2: There are two possibilities, either set an engine order or a number of points per electrical period.

For transient computations the minimum needed number of points per electrical period is 40.

So, when the engine order is not high enough to reach this constraint It is automatically modified to get 40 computation points per electrical period.

3.3.3.2 Maximum mode / spatial order

The “**max. mode / spatial order**” (*Maximum mode / spatial order*) input allows the user to define the number of modes to be considered for the acoustic structural analysis. If the user selects 25, it means that the highest number of lobes in the stator deformation will be equal to 25 lobes. All deformations corresponding to more than 25 lobes will be dismissed.



3.3.3.3 Number of computations per tooth pitch

The “**No. comp./tooth pitch**” (*Number of computations per tooth pitch*) allows to choose the number of Maxwell pressure evaluations per tooth. The more points selected, the more accurate the Maxwell pressure harmonic decomposition will be.

3.3.3.4 Number of points for speed interpolation

The “**No. points for speed interpolation**” (Number of points for speed interpolation) allows to manage the computation of the sound power level per engine order. It allows to manage the data interpolation between the speeds indicated as inputs. Thanks to that, the curves “Sound power level per engine order versus speed” and “weighted sound power level versus speed” can have a better discretization which leads to a better displaying of the local peaks.

The default value is equal to 100. The range of possible values is [50,300]

3.3.3.5 Number of rotor turns

This input allows us to define the number of rotor revolutions to consider the slip as far as possible.

Higher is the number of rotor revolutions better will be the results. However, this value has a huge impact on the computation time.

The default value is equal to 5. This is a good compromise between computation time and quality of results.

The variation range of values for this parameter is [1; 10].

3.3.3.6 Mesh order

To get the results, the original computation is performed using a Finite Element Modeling.

Two levels of meshing can be considered for this finite element calculation: first order and second order.

This parameter influences the accuracy of results and the computation time.

By default, second order mesh is used.

3.3.3.7 Airgap mesh coefficient

The advanced user input “**Airgap mesh coefficient**” is a coefficient which adjusts the size of mesh elements inside the airgap. When the value of “**Airgap mesh coefficient**” decreases, the mesh elements get smaller, leading to a higher mesh density inside the airgap, increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux® software, is described as:

$$\text{MeshPoint} = (\text{airgap}) \times (\text{airgap mesh coefficient})$$

Airgap mesh coefficient is set to 1.5 by default.

The variation range of values for this parameter is [0.05; 2].

0.05 giving a very high mesh density and 2 giving a very coarse mesh density.

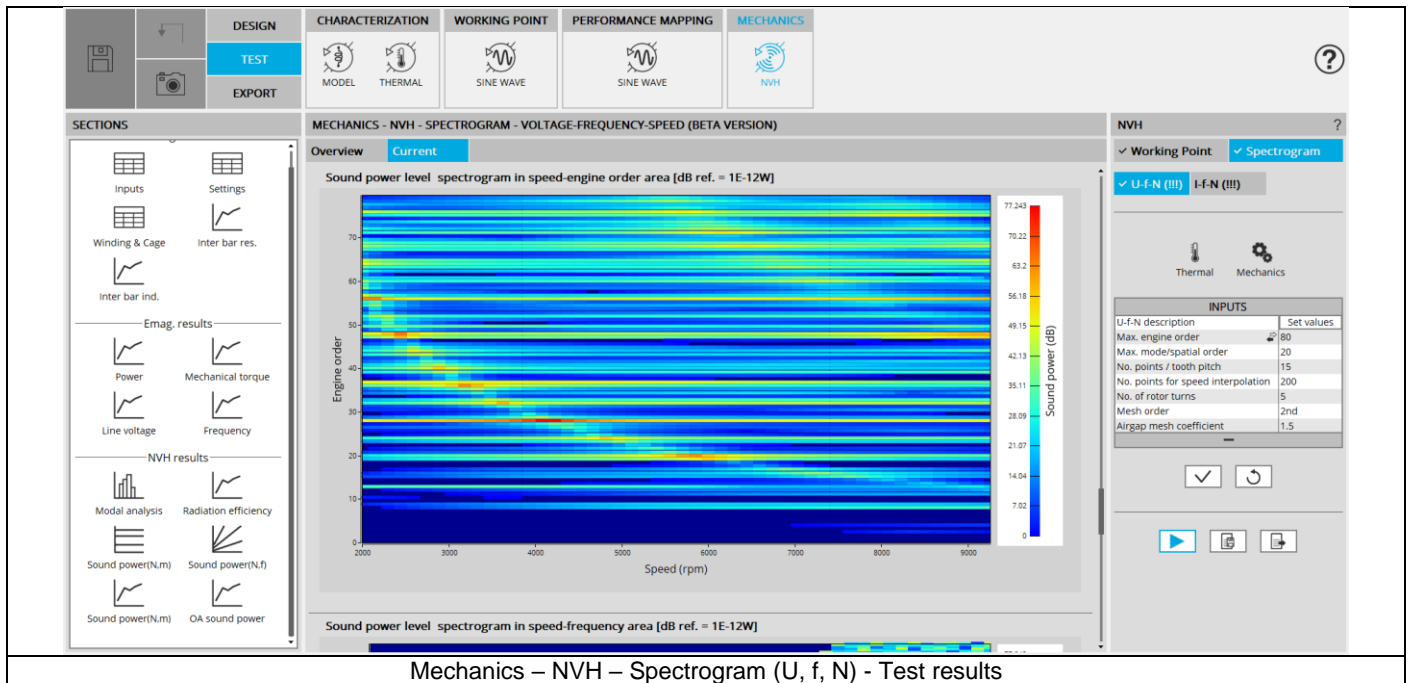
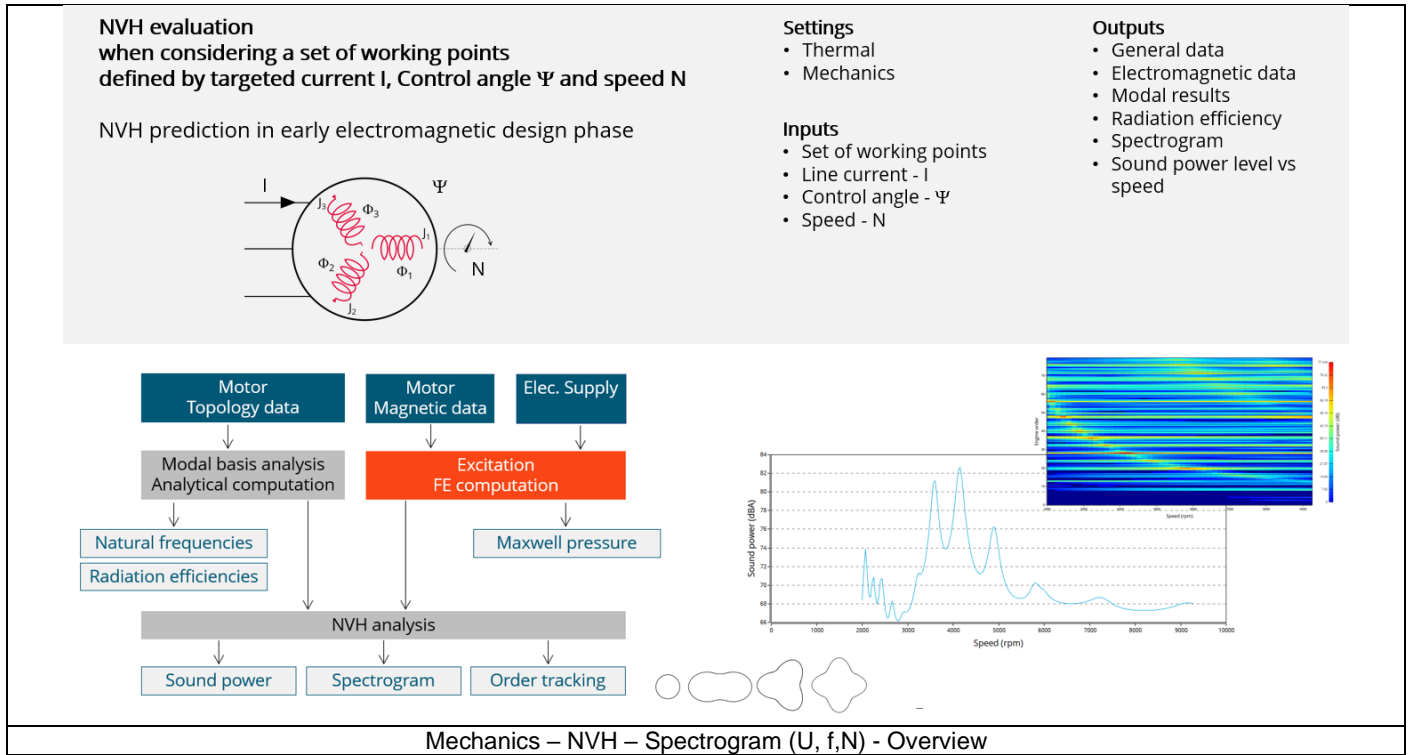
Caution:

Be aware, a very high mesh density does not always mean a better result quality. However, this always leads to a huge number of nodes in the corresponding finite element model. So, it means a need of huge numerical memory and increases the computation time considerably.

3.4 Main principles of computation

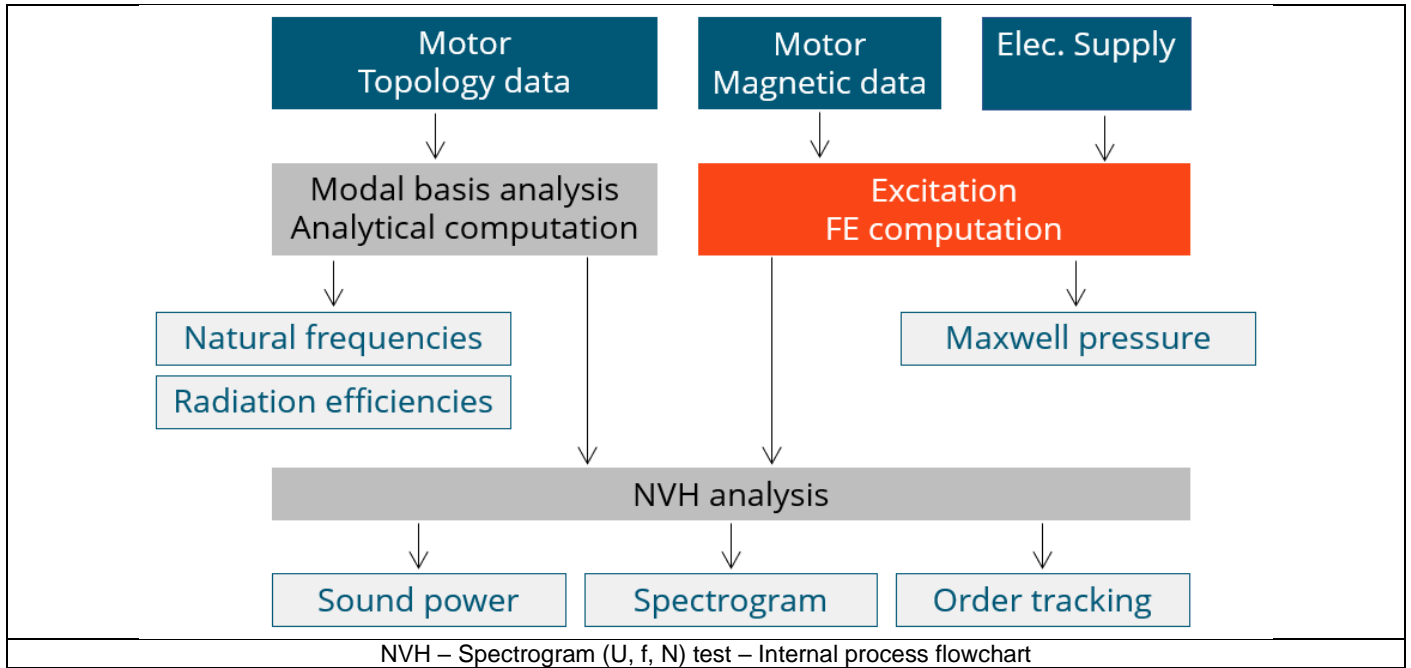
3.4.1 Introduction

Here are illustrations which give an overview of the test NVH – Spectrogram (U,f,N):



3.4.2 Flow chart

Here is the flowchart illustrating the internal process of the thermal test.



The inputs of the internal process are the parameters of:

- Motor topology data
- Motor magnetic data
- Electrical supply

For each point of the U-f-N description, the process described in the previous test is performed. Once it is done, interpolations between the targeted working points are made to produce a high-quality order tracking/ spectrogram graph.

3.5 Test results

3.5.1 Introduction

Before analyzing the test results, take care of advices for use reminded in the section 3.6 (Limitation of computations - Advice for use).

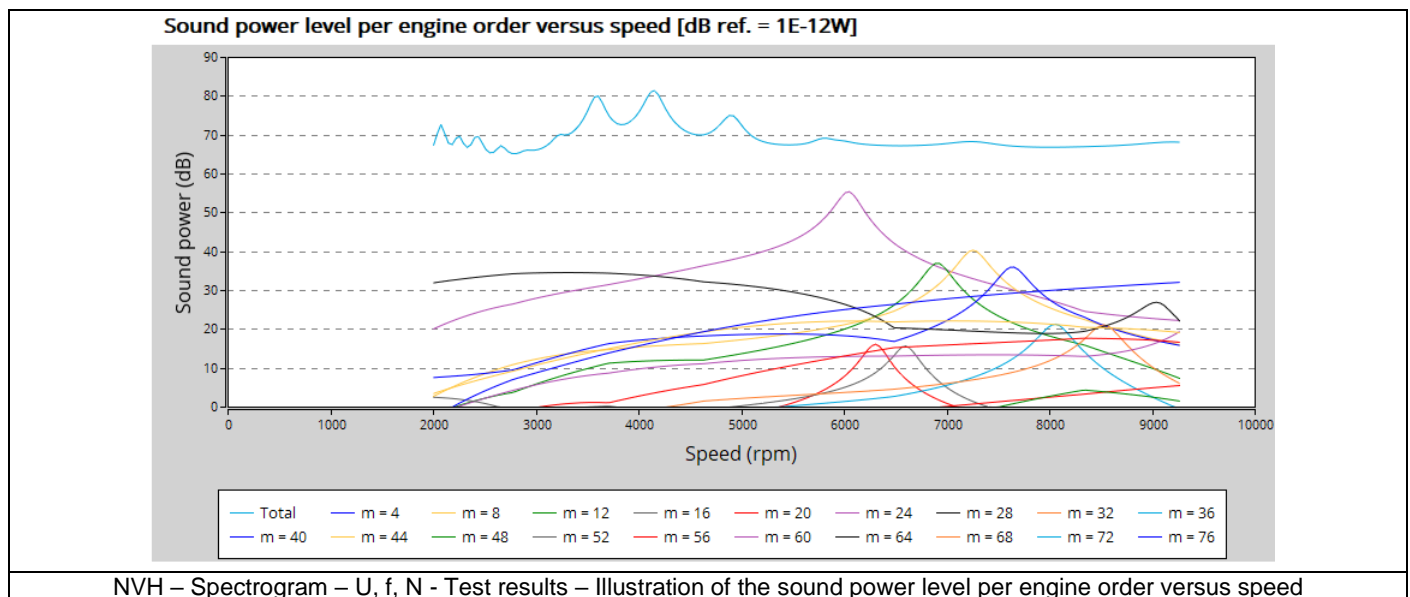
Electromagnetic results are computed and displayed to illustrate and to characterize the considered working points at an electromagnetic point of view.

Data like Mechanical torque, Power, Line current and control angle are displayed versus the speed.

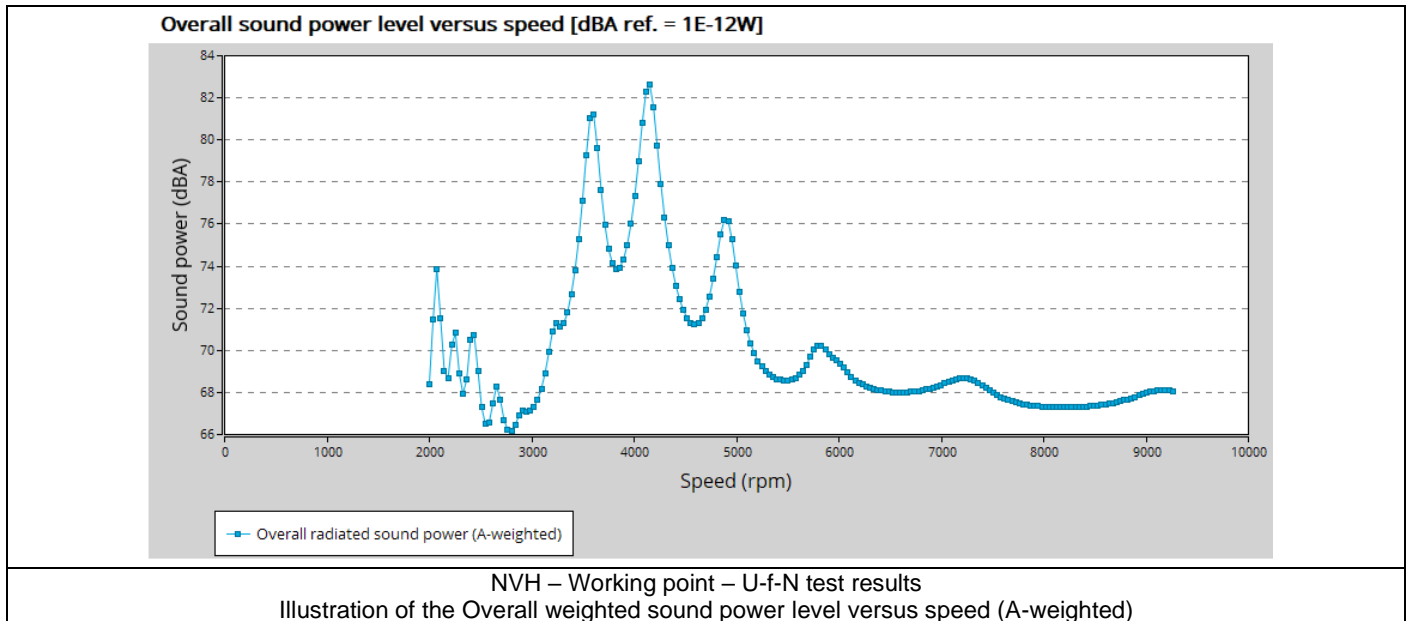
Accordingly, the user inputs a list of several working points which is considered to compute the spectrogram. Each working point is computed by means of Finite Element computations with electromagnetic transient application.

3.5.2 List of the main NVH results

- 1) Modal analysis – Natural frequency versus number of lobes: This graph displays the natural frequency corresponding to the n-lobe deformation.
- 2) Radiation efficiency – Acoustic radiation factor versus frequency: This graph illustrates the capacity of the stator to convert vibration into noise.
- 3) Sound power level spectrogram in speed-engine order area: This spectrogram displays the sound power level in an engine order/speed area. Only the relevant engine orders are displayed (the multiples of the number of poles of the engine).
- 4) Sound power level spectrogram in speed frequency area: This spectrogram displays the sound power level in a frequency/speed area. Only the relevant engine orders are displayed (the multiples of the number of poles of the engine).
- 5) Sound power level per engine order versus speed: This graph displays the sound power level per engine order as well as the total sound power level.



- 6) Overall weighted sound power level versus speed: This graph displays the sound power level weighted for the human ear (A-weighted).



3.6 Limitation of computations - Advice for use

The modal analysis as well as the radiation efficiency are based on an analytical computation where the stator of the machine is considered as a vibrating cylinder.

The considered cylinder behavior is weighted by the additional masses like the fins or the winding and the subtractive masses like the slots and the cooling circuit holes.

This assumption allows to get fast evaluation of the behavior of machine in connection to NVH. In no way this can replace a mechanical Finite Element modeling and simulation.

Among possible reasons for deviations of results can be the following ones:

- The limits of the analytical model are reached or overpassed
- Unusual topology and/or dimensions of the teeth/slots
- Complexity of the stator-frame structure when it is composed with several components for instance
- The ratio between the total length of the frame L_{frame} and the stack length of the machine L_{stk} in any case, this ratio must be lower than 1.5:

$$\frac{L_{Frame}}{L_{Stk}} \leq 1.5$$

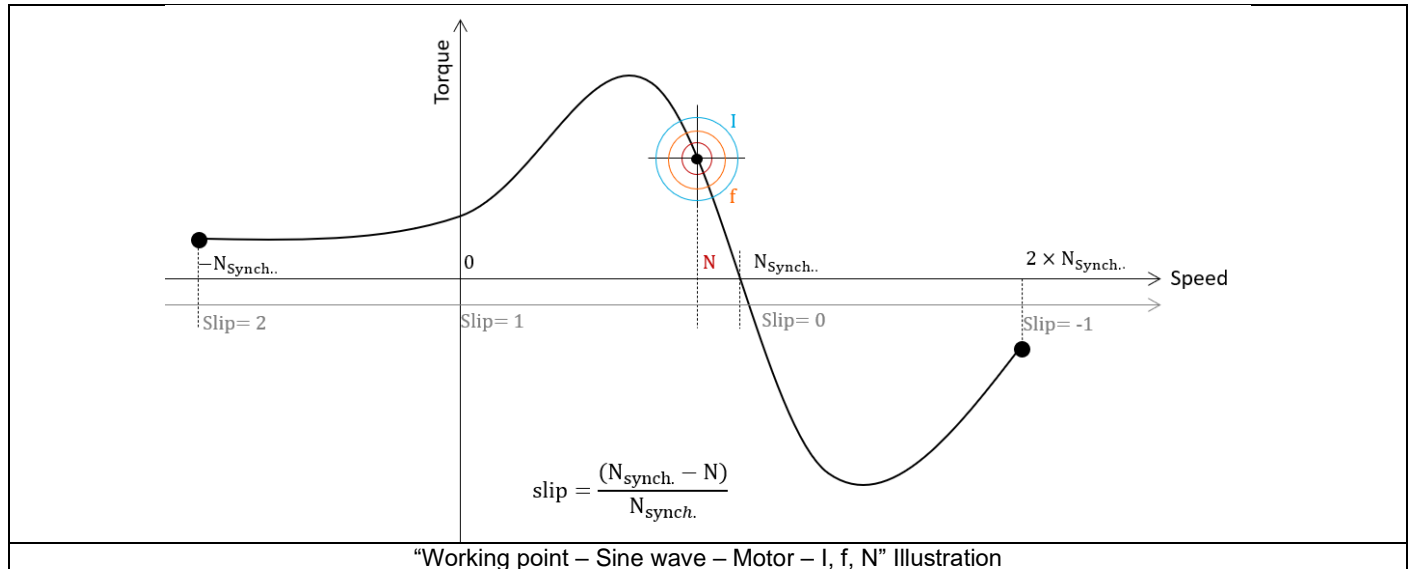
4 MECHANICS – NVH – SPECTROGRAM – I - F - N

4.1 Overview

4.1.1 Positioning and objective

The aim of the test “Mechanics – NVH – Spectrogram – I-f-N” is to perform NVH analysis on the machine when operating at a set of targeted working points defined with the following inputs values U, f, N (Line-Line voltage, Power supply frequency, Speed).

This test is available only in the beta mode. It means that all the computation process and results are not entirely qualified yet. However, this gives users, the capability to use and to evaluate this new feature by themselves.



This test give data allowing NVH prediction in early electromagnetic and design stage.

The modal analysis of the stator mechanical structure, the sound power level spectrogram per engine order versus speed and the resulting overall weighted sound power level versus speed are computed and displayed.

These results allow to see if there are any problems linked with NVH over the considered speed range.

And finally, this test helps to answer the following question:

- Could the machine have any risks in connection with NVH? Yes / No.

The following table helps to classify the test “Mechanics – NVH – Spectrogram – I-f-N”.

Family	Mechanics
Package	NVH
Convention	#
Test	Spectrogram - I - f - N

Positioning of the test “Mechanics – NVH – Spectrogram – I-f-N”

4.1.2 User inputs

The three main user input parameters are the line current, the power supply frequency, and the speed (or the slip). In addition, temperatures of winding and squirrel cage must be set.

Test results are illustrated with data, graph, and tables. Please, refer to the test “Mechanics – NVH – Working point – U-f-N” to get information.

4.2 Settings

Two buttons give access to the following setting definition:

- Temperature of active components: winding and squirrel cage
- Definition of mechanical loss model parameters

For more details, please refer to the document: [MotorFactory_2023_IMSQ_IOR_3PH_Test_Introduction](#).

4.3 Inputs

4.3.1 Introduction

The total number of inputs is equal to 7.

Among these inputs, 1 is a standard input and 6 are advanced inputs.

Note that the standard input corresponds to a table to be filled with a set of working point described as indicated in the following section.

4.3.2 Standard inputs

4.3.2.1 I-f-N description

The “**I-f-N description**” allows to define several working points.

The description must be defined by clicking on the button “Set values”.

Then, two ways are possible to fill in the table: either filling the table line per line or by importing an Excel file in which all the working points to be considered are defined.

Note 1: There must be at least two working points.

Note 2: The speed column must contain increasing speeds.

Each working point is described by the following data:

1) Line current, rms

The rms value of the line current supplying the machine: “**Line current, rms**” (*Line current, rms value*) must be provided.

Note: The number of parallel paths and the winding connections are automatically considered in the results.

2) Power supply frequency

The value of the power supply frequency of the machine: “**Power supply frequency**” (*Power supply frequency*) must be provided.

The power supply frequency is the electrical frequency applied at the terminals of the machine.

4.3.2.2 Definition mode

There are 2 common ways to define the working point. It can be defined by indicating the slip “**Slip**” or by defining the operating speed of the machine “**Speed**”.

4.3.2.3 Slip

When the choice of definition mode is “**Slip**”, the value of machine’s slip “**Slip**” (*Slip*) must be provided.

Note: The slip (s) corresponds to the difference between the speed of the rotating magnetic field in the stator (N_s = Synchronous speed) and the rotor operating speed (N).

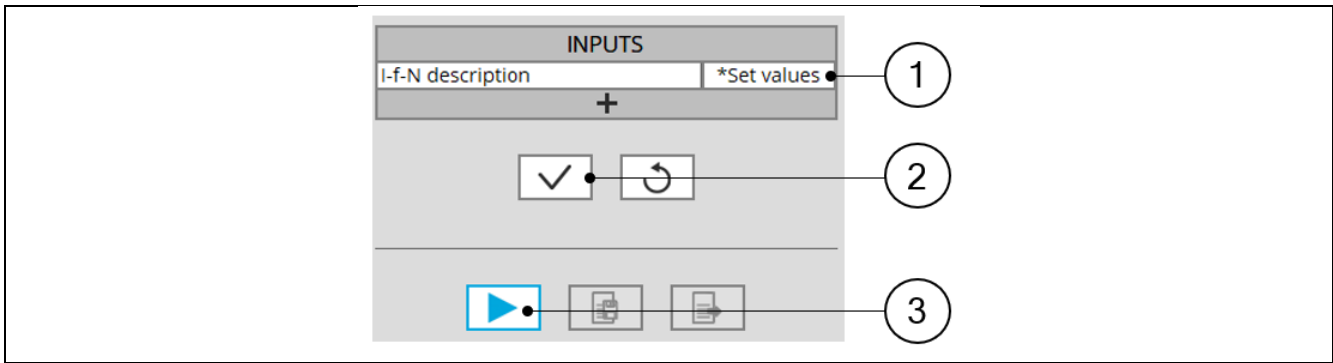
$$s = \frac{N_s - N}{N_s}$$

Unit can be % or PU.

4.3.2.4 Speed

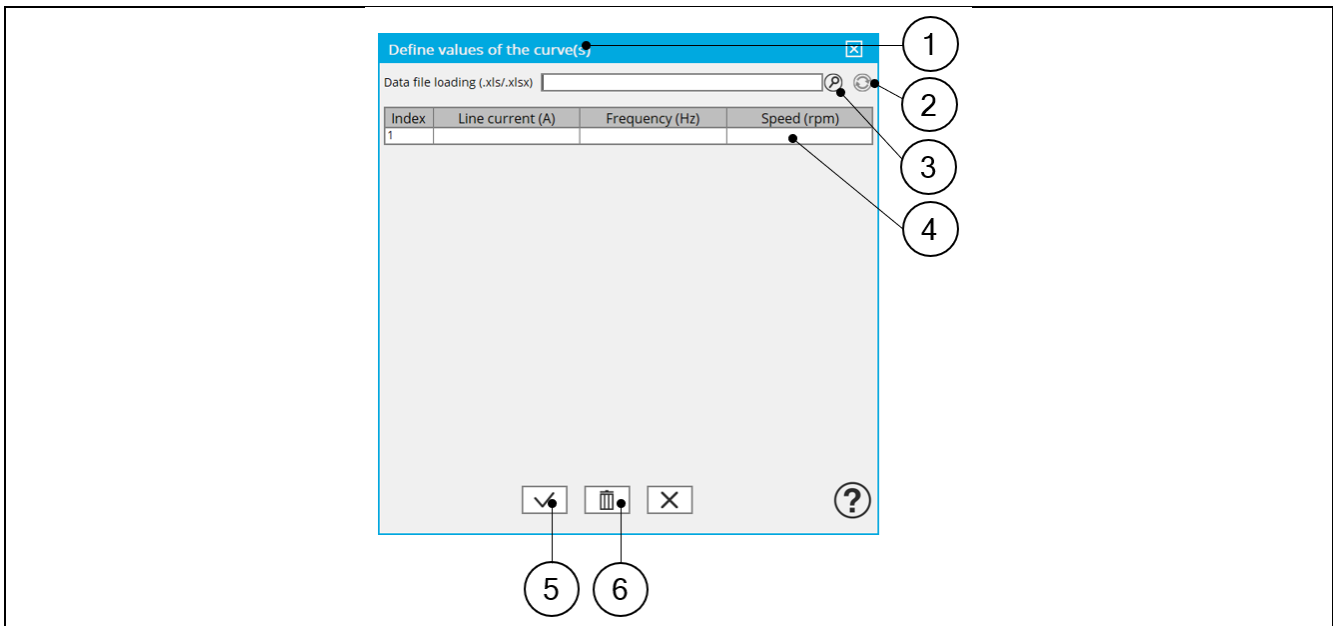
When the choice of definition mode is “**Speed**”, the value of operating speed “**Speed**” (*Speed*) must be provided.

4.3.2.5 Process to define the list of working points



List of working points to be defined

1	Click on the button “Set values” of the field “ I, f, N description” to define the working points in a dialog box. Refer to the next illustration which shows how to fill the working point table.
2	Button to validate the user input data
3	Button to run the computations



Dialog box to define the list of working points

1	Dialog box opened after having clicked on the button “Set values” in the field “Cycle description”
2	Browse the folder to select an Excel file to define the working points to be considered
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the list of working points to be considered

U-f-N input			
Label	current	frequency	Speed
Units	A	Hz	rpm
Values	10	50	1000
	15	200	5000
	20	400	9000

Excel file template to define the list of working points

4.3.3 Advanced input

4.3.3.1 Maximum engine order / No. Points per electrical period

Two kinds of inputs are possible:

Define the **Max. engine order** (*Maximum engine order*) or the **No. points / elec. Period** (*Number of points per electric period*).

When decomposing the Maxwell pressure, applied on the stator, to get its harmonic contributions, the “**max. engine order**” (*Maximum engine order*) is required to compute its decomposition in function of the time.

At a practical point of view, when the maximum engine order is equal to N, that leads to consider $2*N$ computation points over a complete rotation period of the rotor.

Note 1: The input "Engine order" is in connection with the frequency of vibration.

"Engine order" refers to a mechanical revolution period of the motor when frequency refers to the considered electrical period.

Obviously, both are linked with speed.

For instance, sound power level can be displayed either by considering frequency or engine order.

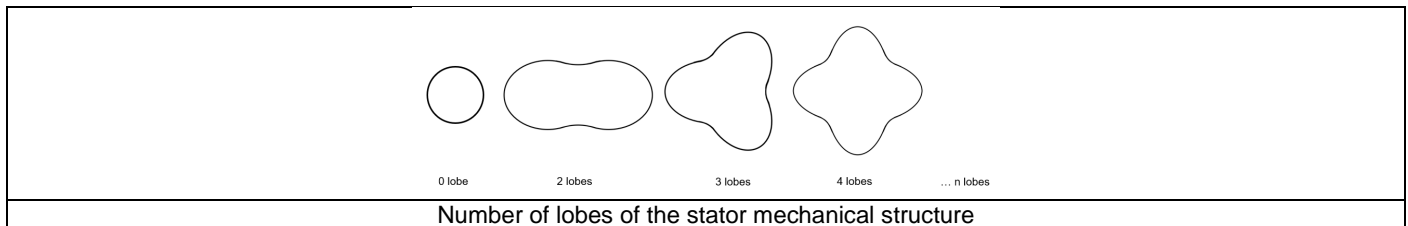
Note 2: There are two possibilities, either set an engine order or a number of points per electrical period.

For transient computations the minimum needed number of points per electrical period is 40.

So, when the engine order is not high enough to reach this constraint It is automatically modified to get 40 computation points per electrical period.

4.3.3.2 Maximum mode / spatial order

The “**max. mode / spatial order**” (*Maximum mode / spatial order*) input allows the user to define the number of modes to be considered for the acoustic structural analysis. If the user selects 25, it means that the highest number of lobes in the stator deformation will be equal to 25 lobes. All deformations corresponding to more than 25 lobes will be dismissed.



4.3.3.3 Number of computations per tooth pitch

The “**No. comp./tooth pitch**” (*Number of computations per tooth pitch*) allows to choose the number of Maxwell pressure evaluations per tooth. The more points selected, the more accurate the Maxwell pressure harmonic decomposition will be.

4.3.3.4 Number of points for speed interpolation

The “**No. points for speed interpolation**” (Number of points for speed interpolation) allows to manage the computation of the sound power level per engine order. It allows to manage the data interpolation between the speeds indicated as inputs. Thanks to that, the curves “Sound power level per engine order versus speed” and “weighted sound power level versus speed” can have a better discretization which leads to a better displaying of the local peaks.

The default value is equal to 100. The range of possible values is [50,300]

4.3.3.5 Number of rotor turns

This input allows us to define the number of rotor revolutions to consider the slip as far as possible.

Higher is the number of rotor revolutions better will be the results. However, this value has a huge impact on the computation time.

The default value is equal to 5. This is a good compromise between computation time and quality of results.

The variation range of values for this parameter is [1; 10].

4.3.3.6 Mesh order

To get the results, the original computation is performed using a Finite Element Modeling.

Two levels of meshing can be considered for this finite element calculation: first order and second order.

This parameter influences the accuracy of results and the computation time.

By default, second order mesh is used.

4.3.3.7 Airgap mesh coefficient

The advanced user input “**Airgap mesh coefficient**” is a coefficient which adjusts the size of mesh elements inside the airgap. When the value of “**Airgap mesh coefficient**” decreases, the mesh elements get smaller, leading to a higher mesh density inside the airgap, increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux® software, is described as:

$$\text{MeshPoint} = (\text{airgap}) \times (\text{airgap mesh coefficient})$$

Airgap mesh coefficient is set to 1.5 by default.

The variation range of values for this parameter is [0.05; 2].

0.05 giving a very high mesh density and 2 giving a very coarse mesh density.

Caution:

Be aware, a very high mesh density does not always mean a better result quality. However, this always leads to a huge number of nodes in the corresponding finite element model. So, it means a need of huge numerical memory and increases the computation time considerably.

4.4 Main principles of computation

Same principles of computation than in the test “Mechanics – NVH – Working point – U-f-N”.

4.5 Test results

Same results than in the test “Mechanics – NVH – Working point – U-f-N”

4.6 Limitation of computations - Advice for use

The modal analysis as well as the radiation efficiency are based on an analytical computation where the stator of the machine is considered as a vibrating cylinder.

The considered cylinder behavior is weighted by the additional masses like the fins or the winding and the subtractive masses like the slots and the cooling circuit holes.

This assumption allows to get fast evaluation of the behavior of machine in connection to NVH. In no way this can replace a mechanical Finite Element modeling and simulation.

Among possible reasons for deviations of results can be the following ones:

- The limits of the analytical model are reached or overpassed
- Unusual topology and/or dimensions of the teeth/slots
- Complexity of the stator-frame structure when it is composed with several components for instance
- The ratio between the total length of the frame L_{frame} and the stack length of the machine L_{stk} in any case, this ratio must be lower than 1.5:

$$\frac{L_{\text{Frame}}}{L_{\text{Stk}}} \leq 1.5$$