

<https://www.eomys.com/produits/manatee/howtos/article/how-to-find-the-root-cause-of-magnetic-noise-and-vibrations-in-electric>



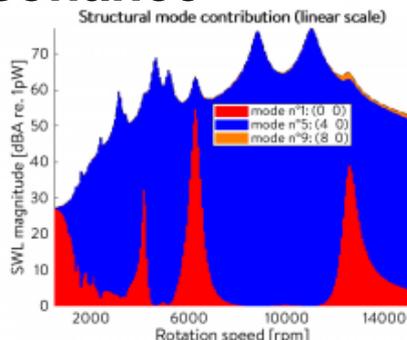
How to find the root cause of magnetic noise and vibrations in electric machines using MANATEE?

- Products - MANATEE - Howtos -
Publication date: Friday 13 January 2017

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MANATEE software offers several tools to quickly identify the **root cause of acoustic noise and vibrations** in terms of nature (forced or resonant mode) and physical origin (e.g. flux density harmonics involved in vibration, radial or tangential force). This article presents the post processing which can be used to identify the origin of electromagnetically-excited noise and vibration and take appropriate [noise control actions](#).

Identification of resonance



NVH root cause analysis using modal participation factors calculated in MANATEE software

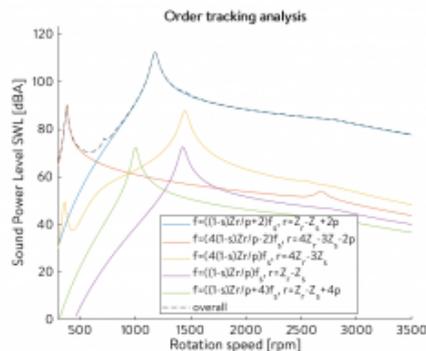
To identify if the noise (resp. vibration) is coming from a particular resonance with a structural mode, the best is to plot the **contribution of the structural modes to the overall noise level** (resp. vibration) level as a function of speed. This can be done with the post processings [plot VS ASWL modal contribution](#) for noise (or [plot Ar modal cont](#) for vibration). If a resonance involves a lamination mode (2,0) it means that the harmonic magnetic force has a [wavenumber](#) $r=2$. This graph therefore gives an idea of both the critical speeds and the magnetic [force wavenumbers](#) involved in noise generation.

The difference between **forced and resonant regimes** can be done looking at static versus dynamic radial vibration velocity. The corresponding post processings are [plots Vr fft](#) (dynamic) and [plot Vr static fft](#) (static). Similarly the static radial displacement FFT2 [plot Ur static fft2](#) can be compared with the dynamic radial displacement FFT2 [plot Ur fft2](#).

One can also check at a given speed the Fourier content of radial and tangential forces using [plot Fr fft2](#) and [plot Ft fft2](#). This post processing displays the lamination structural mode on the top of the Fourier transform of forces, so one can also check if the **resonance condition** is fulfilled (match between wavenumber r and mode circumferential order m + match between exciting force frequency f and mode natural frequency).

Analysis of force frequency and wavenumber

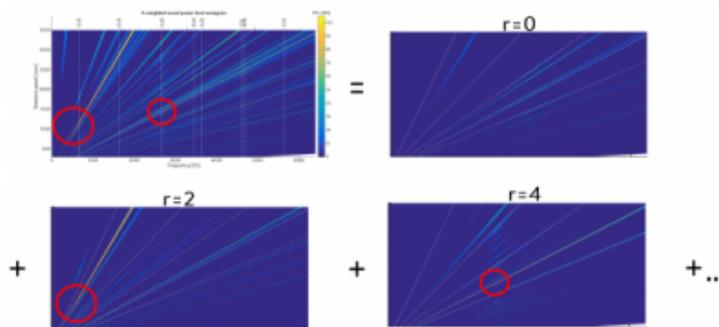
To identify more precisely the electrical frequency and [wavenumber](#) of the Maxwell force harmonic responsible for high noise and vibration levels, one can use the at variable speed the **order tracking analysis** with [plot VS ASWL order analysis](#).



Noise reduction of electric motors using Order Tracking Analysis in MANATEE software

For some topologies (e.g. SCIM) the analytical formula of the exciting force frequency and wavenumber corresponding to the numerical excitation are displayed. This expression can then be related to the **physical origin of the magnetic force**.

As an example, if the order tracking analysis shows that the vibration or noise line frequency is $f=fs(Zr/p+2)$ the multiplication factor in front of Zr corresponds to the rank of the rotor slotting permeance harmonic. Similarly, a line labelled with $r=2Zs-4p$ means that the wavenumber of the harmonic force is related to the second rank of stator slotting permeance. The rank of permeance Fourier expression is important when optimizing the slot opening or the skewing.



Electric motor noise reduction using spatiogram technique in MANATEE software

To directly discriminate different [wavenumbers](#) in a noise or vibration [spectrogram](#) it is advised to use **MANATEE key post processing of spatiograms** with the plot command [plot_VS_ASWL_spatiogram](#).

Finally, all these interpretations can be compared to the [theoretical analysis of magnetic resonances](#) provided in the text output of the simulation.

Effect of the load

One important thing to understand is if the **noise is coming from load-related harmonics or not**. In particular, in PMSM the armature field is responsible for some specific magnetic forces. To discriminate the noise due to partial load operation from the noise due to open circuit operation one can simply cancel out the armature field by imposing null current or by **cancelling the calculation of the armature field** with

```
is_mmfs=0
```

Identification of flux density harmonics involved in noise generation

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Some useful scripts are also provided to automatically **find the permeance / magnetomotive force harmonics** that can be the cause of a given force/vibration/noise harmonic in each topology. As an example the script `find_harmonic_PMSM_open_circuit_rf(r, f, p, Zs, freq0)` displays all the harmonics responsible for a given magnetic force in open circuit. For a machine with $p=7$ and $Zs=12$, a force at twice the electrical frequency ($2fs$) and wavenumber $r=2$ appears. To find the origin of these harmonics at open circuit the command line

```
find_harmonic_PMSM_open_circuit_rf( 2, 2, 7, 12)
```

returns the following text output:

```
Force wave (f=2fs, r=2) is created by the product of flux waves B1=P1.F1 and B2=P2.F2 such as:  
B1=(0,0).(fs,p) and B2=(0,-2e).(fs,p)  
B1=(0,0).(fs,p) and B2=(0,-2e).(3fs,3p)  
B1=(0,2e).(fs,p) and B2=(0,-2e).(fs,p)  
B1=(0,2e).(fs,p) and B2=(0,-2e).(3fs,3p)  
B1=(0,-2e).(fs,p) and B2=(0,-2e).(3fs,3p)  
B1=(0,3e).(fs,p) and B2=(0,-6e).(fs,p)
```

At partial load the corresponding command line is

```
find_harmonic_PMSM_partial_load_rf( 2, 2, 7, 12)
```

The command can be used for both inner and outer rotor application. For outer rotor topologies one should put the fifth argument to 1 and type

```
find_harmonic_PMSM_partial_load_rf( 2, 2, 7, 12, 1)
```

The full list of all main stress harmonics (including tooth modulation effect) can be established with

```
find_harmonic_PMSM_open_circuit(p,Zs)  
find_harmonic_PMSM_partial_load(p,Zs,qs)
```

Extensive harmonic analysis

Identifying the critical speed, frequency and [wavenumbers](#) of magnetic forces is not enough to carry noise mitigation action. A key question is which specific **field harmonic (rotor Vs stator)**, **permeance harmonic** and **magnetomotive force harmonic** is responsible for noise.

To carry this full analysis automatically, a special simulation mode called [automated harmonic analysis](#) can be activated in MANATEE with `Input.Simu.type_harm_analysis =1`.

This option is demonstrated in validation projects ALG_011 and ALG_012. The principle of the harmonic analysis is to simulate all the possible combination of harmonic sources by turning on and off the following sources of harmonics:

- PWM (enforcing sinusoidal voltage operation)
- rotor field ([cancellation of rotor magnetic field](#))
- stator field ([cancellation of stator magnetic field](#))
- rotor winding harmonics ([cancellation of rotor mmf space harmonics](#))
- stator winding harmonics ([cancellation of stator mmf space harmonics](#))
- rotor slotting harmonics ([cancellation of rotor induced permeance harmonics](#))
- stator slotting harmonics ([cancellation of stator induced permeance harmonics](#))

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This type of analysis can also be carried manually by switching off and on these harmonic sources and check the impact on NVH behaviour.

Harmonic interferences (advanced)

The **constructive and destructive interferences** between radial flux or tangential flux harmonics can be studied more quantitatively on a given radial (resp. tangential) force harmonic with [plot Fr vectors](#) (resp. [plot Ft vectors](#)). This allows to identify the combination of flux density waves creating a given magnetic force harmonic.

To go further, one can identify the combination of permeance / magnetomotive force waves creating a given flux harmonic using [plot Br vectors](#) (resp. [plot Bt vectors](#));

Cancellation of some specific harmonics (advanced)

To go further, if a special combination of permeance / mmf harmonic and flux density harmonic has been identified as a key contributor of magnetic noise and vibration, one can check that it is the case by **cancelling a specific set of harmonics**. This analysis can be carried using the dedicated [harmonic cancellation tool](#).

Radial Vs tangential effects (advanced)

To identify whether noise / vibration is mainly due to radial forces or tangential forces, one can cancel tangential forces by using

```
Input.Simu.is_forcetang=0
```

This way the tangential FRF are cancelled and one can compare noise with and without tangential forces.

The respective contribution of radial & tangential field to the radial Maxwell stress can also be studied by using

```
Input.Simu.is_approx_rad=0
```

in this case the Maxwell radial force is calculated using both radial and tangential airgap flux density. With *Input.Simu.is_approx_rad=1* the radial Maxwell stress is directly proportional to the square of the radial flux density.