evs 27

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.
Barcelona, Spain
17th-20th November 2013

LMS A Siemens Business

NVH analysis of a 3 phase 12/8 SR motor drive for HEV applications

Mathieu Sarrazin[1], Steven Gillijns[1], Jan Anthonis[1], Karl Janssens[1], Herman van der Auweraer[1], Kevin Verhaeghe[2]

[1]*LMS, a Siemens Business (BE)*

[2]*Inverto NV (BE)*

Organized by Fira Barcelona avele

Hosted by AVERE mea Ajuntament de Barcelona

In collaboration with EVAAP EDTA

Supported by European Commission

Presentation Outline

- **Introduction**
- **Experimental setup**
- **Vibro-acoustic study** based on experimental data
  - **Signature** time and frequency **analysis**
  - **Deflection shapes** and time domain animation
  - **Sound quality evaluation**
- **Conclusion**

Introduction

Electric motor overview:

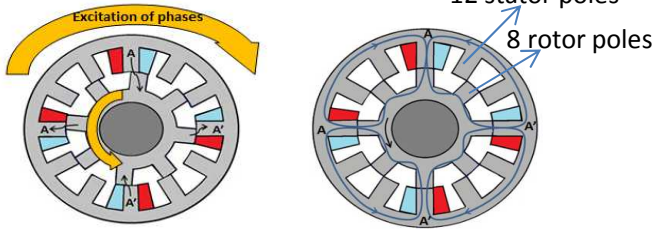
- **World of Electrical Machines**
  - **DC motor**
    - **Brush DC**
      - Shunt wound
      - Separately excited
      - Series wound
      - Compound wound
      - Permanent magnet
      - Universal
  - **AC motor**
    - **Induction**
      - Squirrel cage
      - Wound rotor
    - **Synchronous**
      - Permanent magnet
      - Variable reluctance
      - **Switched reluctance**
      - Hybrid synchronous
    - **Linear**
      - Induction
      - Synchronous
      - …

Salient advantages of SRMs:

- Simple, robust and low-cost construction
- Absence of permanent magnets = higher temperature
- High efficiency in wide speed range
- Intrinsically safe operation

Disadvantage:

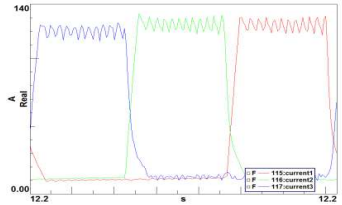
- Acoustic noise and torque ripple are troublesome

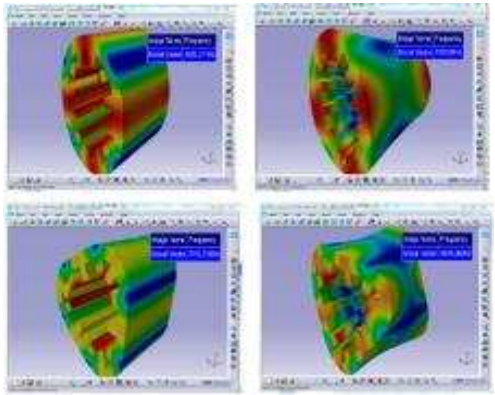


Introduction

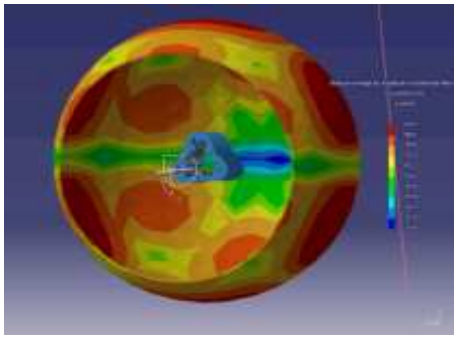
Noise generation process of a SR-motor:

- Phase currents
- Radial forces in the air gap between rotor and stator
- Vibrations of stator due to radial displacement
- Pressure variations in the air, perceived as noise





$$F_r(\theta, l_g, i) = -\frac{1}{2} i^2 \frac{L(\theta, i)}{l_g}$$



The radial attractive force between stator and rotor is the dominant NVH source!

Introduction

Objectives of this research work "Characterization of 3 phase 12/8 SRM":

- **To verify the theory that the square mode is the first excited mode in practice**
  → Modal analysis & operational deflection shapes

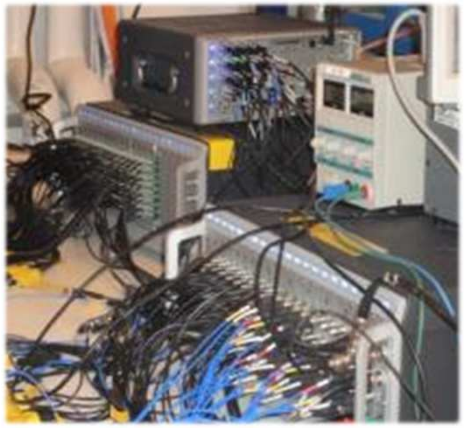
- **To identify the dominant features in different operational conditions**
  → Frequency spectrum/ order sections of current, noise and vibrations signals

- **To assess the tonality, loudness and sharpness of this specific 12/8 SRM**
  → Sound metrics

Experimental Setup

Practical overview:

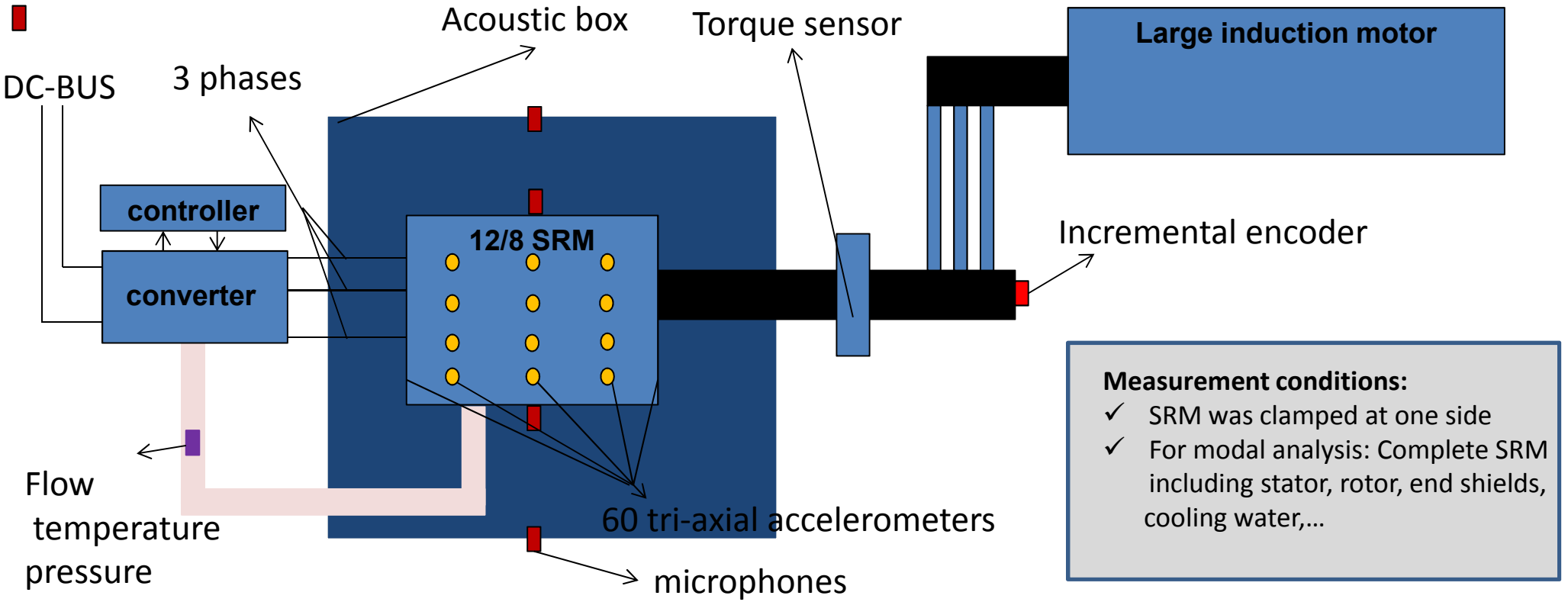
12/8 SRM under test conditions



Total measured channels: **219**

Experimental Setup

Schematic overview:



Measurement conditions:

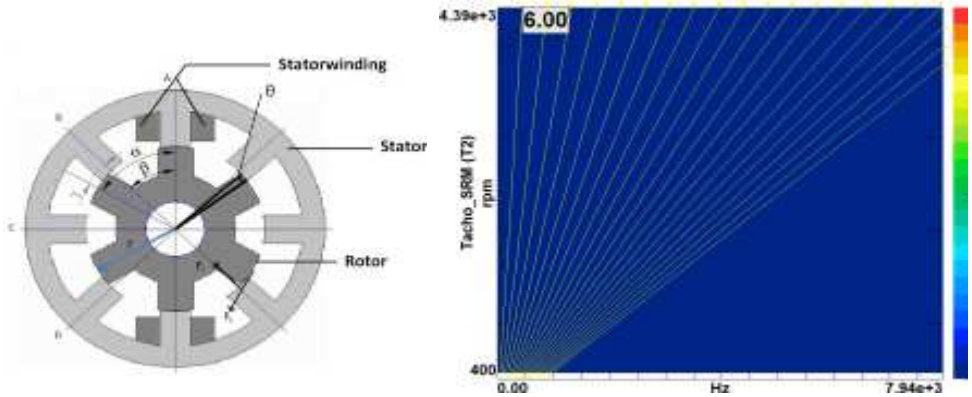
- ✓ SRM was clamped at one side
- ✓ For modal analysis: Complete SRM including stator, rotor, end shields, cooling water,…

Organized by Hosted by In collaboration with Supported by

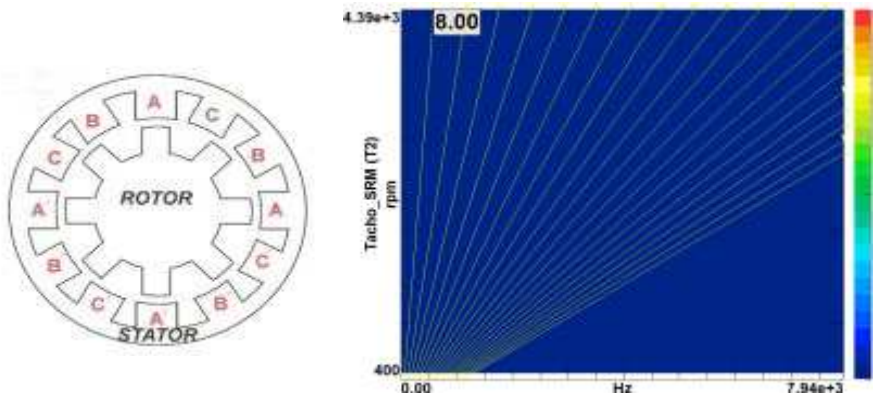
Signature Analysis

Theoretical background signature analysis SRM 8/6 versus 12/8:

8/6 SR-motor



12/8 SR-motor

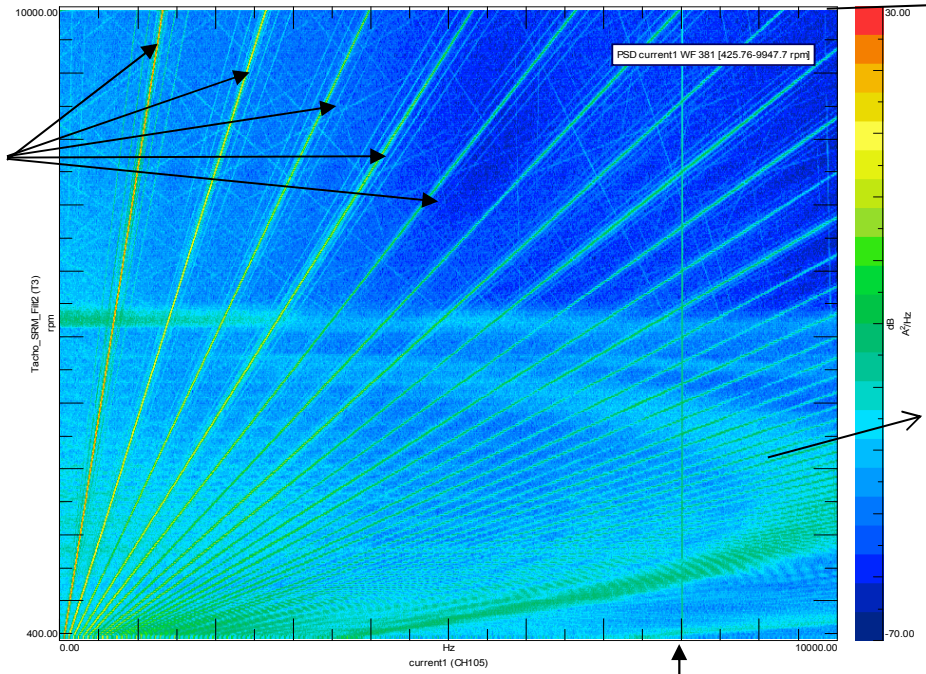


	8/6	12/8
Number of poles excited at the same time	2	4
Number of electric phases	4	3
Total number of phase excitations per revolution	24	24
Fundamental order (= number of times that a phase is excited per revolution)	6	8

Signature Analysis

Frequency spectrum of a phase current profile during run-up:

Dominant orders due to radial force excitation:



Switching frequency angle detection system

The *phase current* i_a, i_b, i_c commutation is the main cause of the torque ripple!

Related to ripple on the current signal

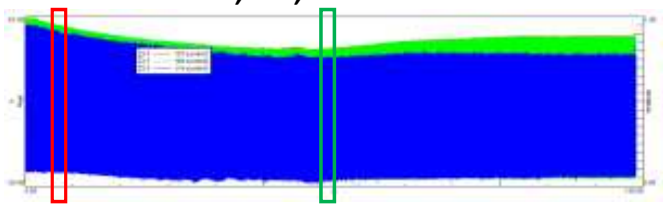
8kHz switching frequency of inverters of load (i.e. IM)

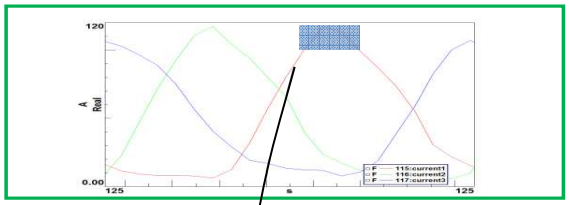
In a 12/8 SRM, each of the 3 phases is excited 8 times per revolution → 8th order harmonics

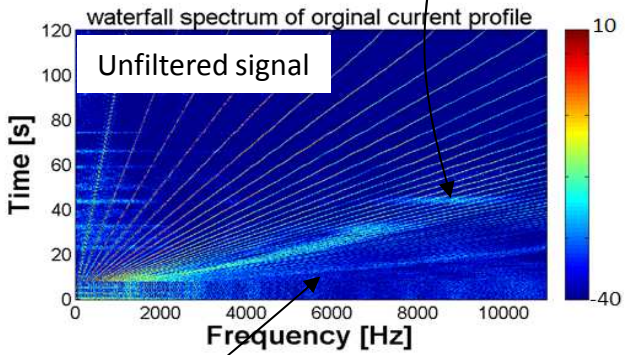
Signature Analysis

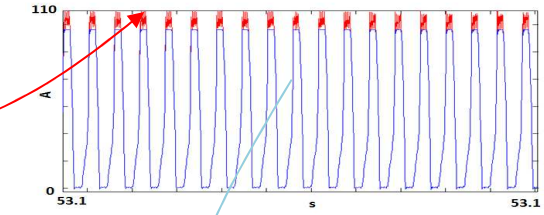
Frequency spectrum of a phase current profile during run-up:

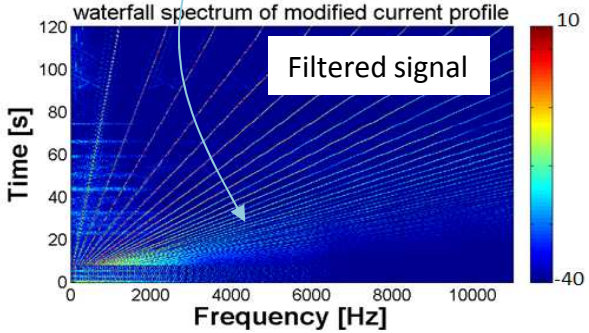
I1, I2, I3

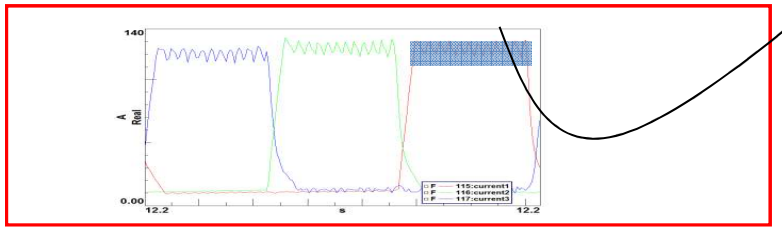






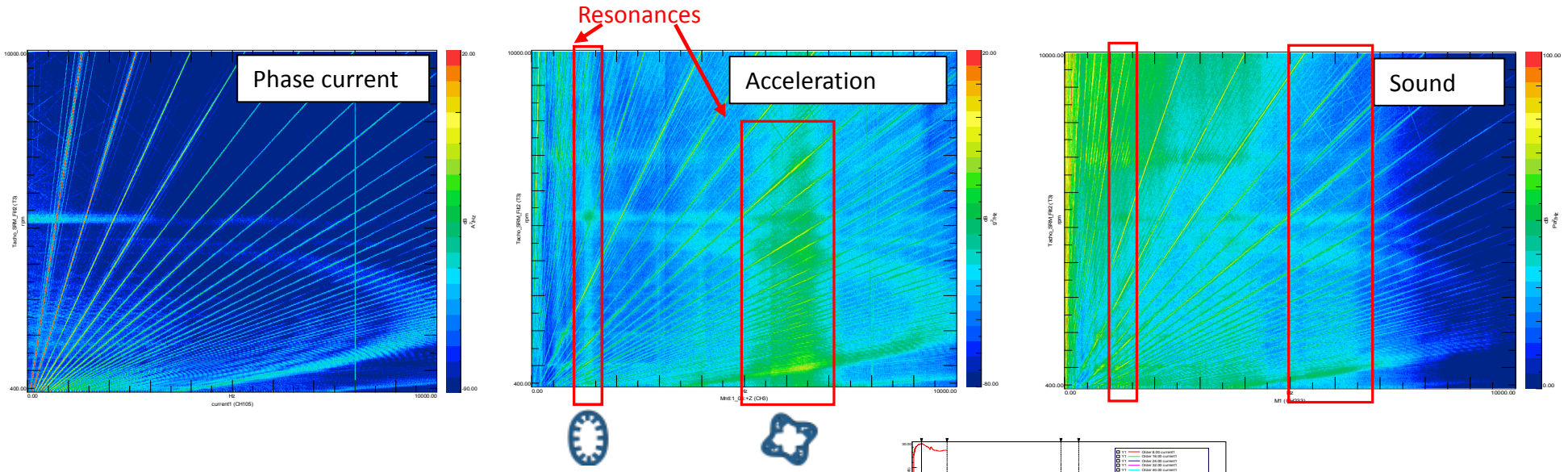




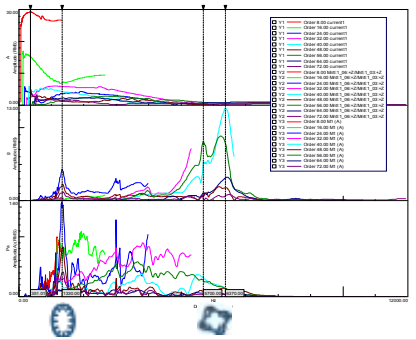


Signature Analysis

Frequency spectrum current versus noise and vibrations signal:

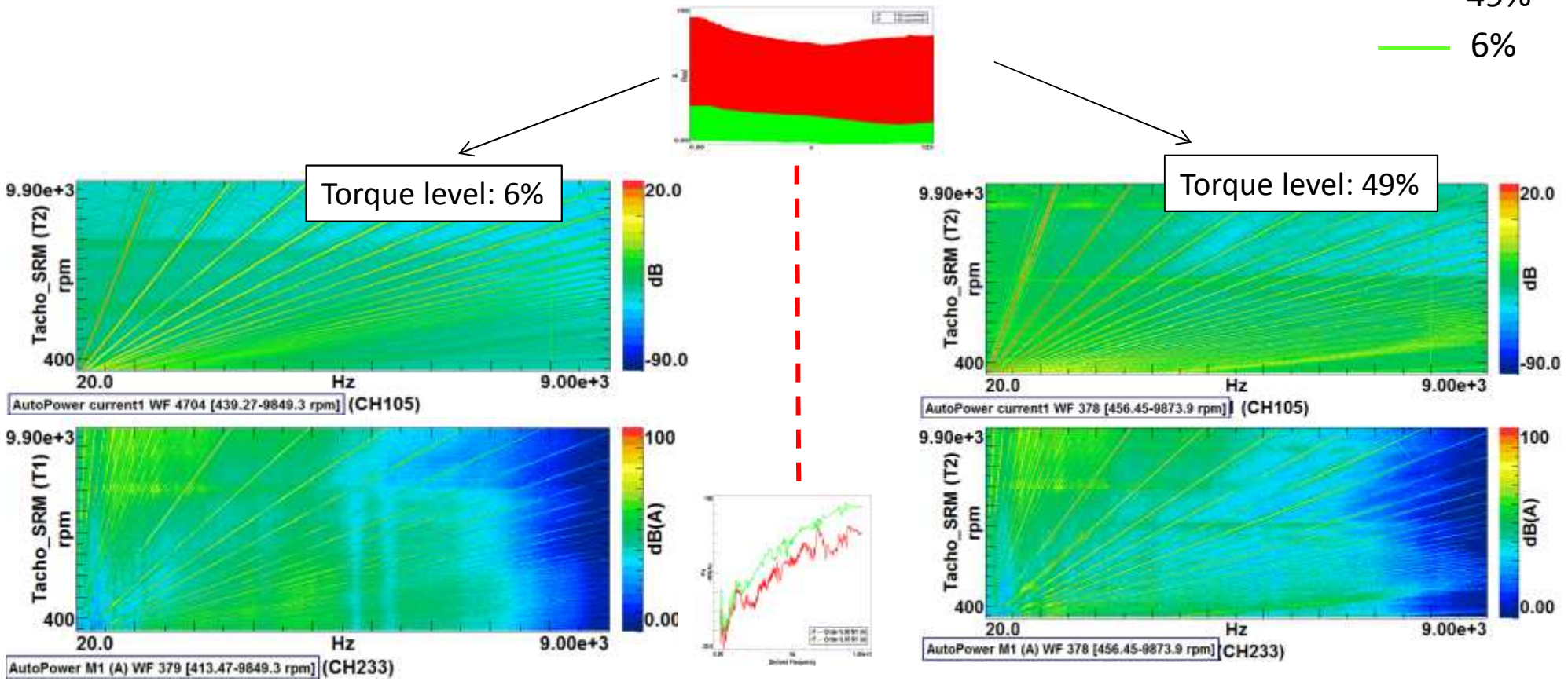


	Current	Acceleration	Sound
Order 8 and multiples	✓	✓	✓
Resonances	x	✓	(✓)



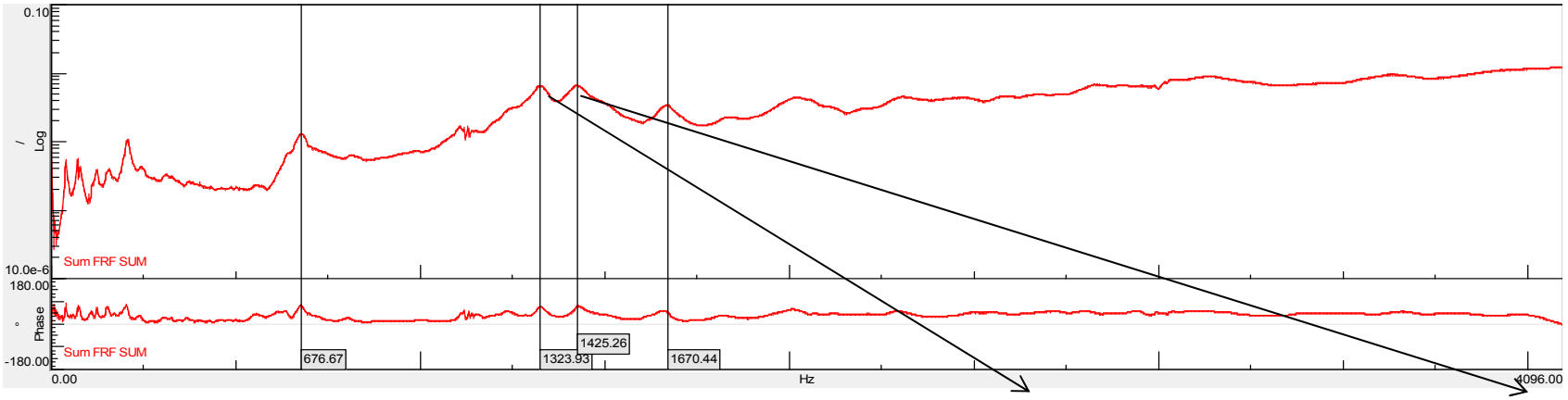
Signature Analysis

Frequency spectrum current signal versus noise and vibrations:

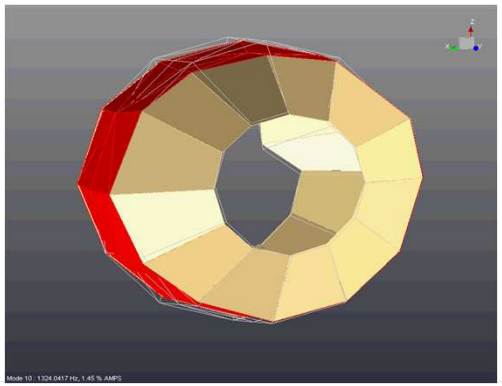


Modal analysis

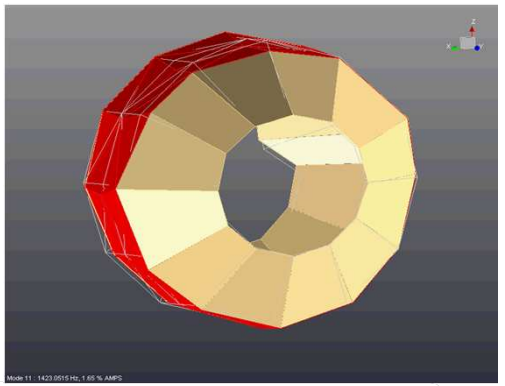
Ovalization mode of the mounted 12/8 SRM:



1324 Hz



1425 Hz

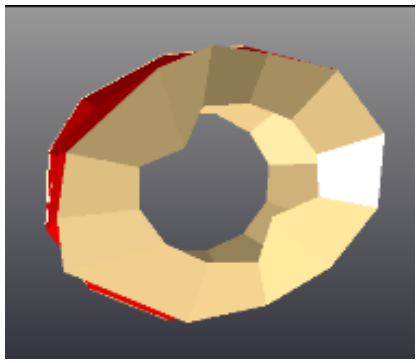


Modal analysis = makes it possible to study the dynamic properties of the structure under excitation (hammer, shaker,…)

Deflection Shapes

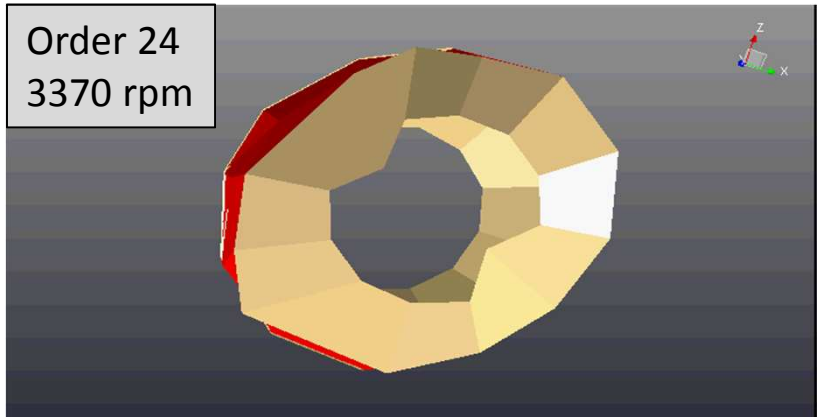
Ovalization mode of the mounted 12/8 SRM:

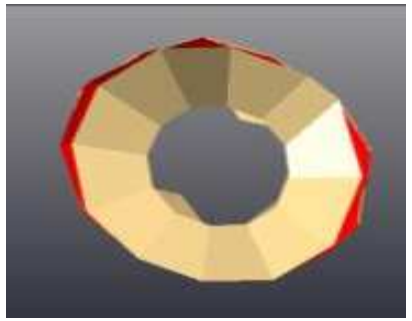
- **Theoretically,** when a phase is excited, 4 stator poles are loaded at the same time => ovalization mode shouldn't be excited during run-up measurement
- **In practice,** it turns out that the ovalization mode is excited
  - Visible in all orders, but best in order 24
  - Ovalization happens at both flanges. Both flanges move in phase with each other.



Ovalization of free end shield

Operating Deflection Shape (ODS) analysis = a useful tool to analyze vibration characteristics of a machine during a run-up.





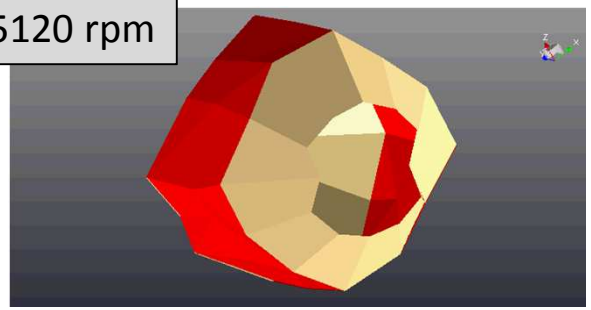
Ovalization of clamped end shield

Deflection Shapes

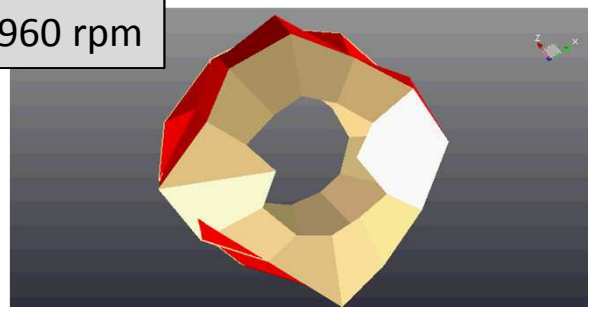
Square mode of the mounted 12/8 SRM:

- **Theoretically,** when a phase is excited, 4 stator poles are loaded at the same time=>square mode should be excited
- **In practice,** visible in all orders but best in order 56

Order 56
5120 rpm

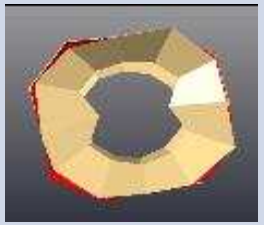


Order 56
5960 rpm

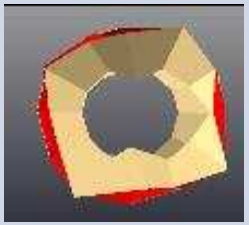


Screenshots

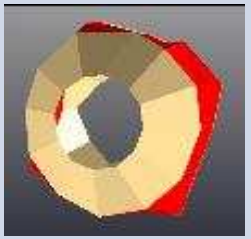
Order 56
5120 rpm



Order 56
5960 rpm



Square deflection of free end shield

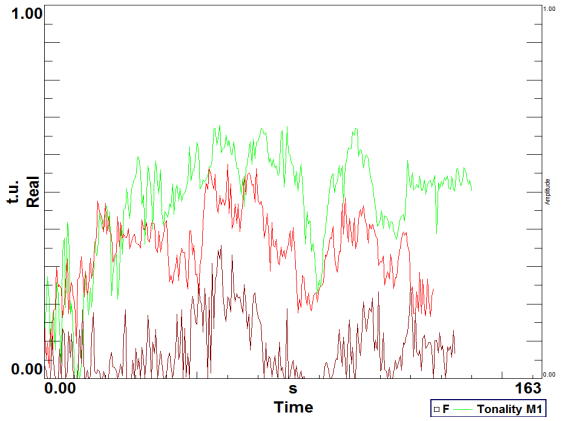


Clamped end shield:
Square deflection

Clamped end shield:
deflection less pronounced

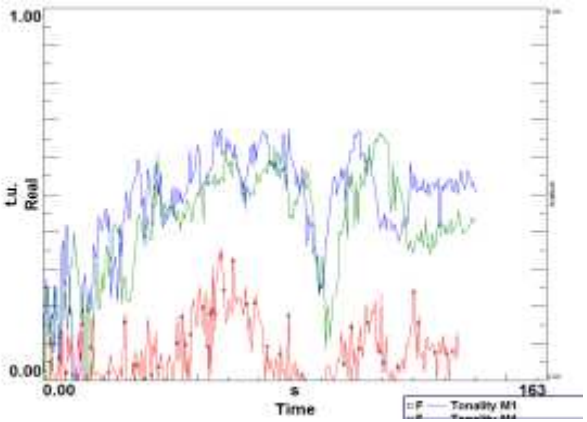
Sound Quality Evaluation

Tonality/sharpness/Loudness:

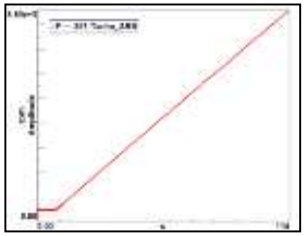


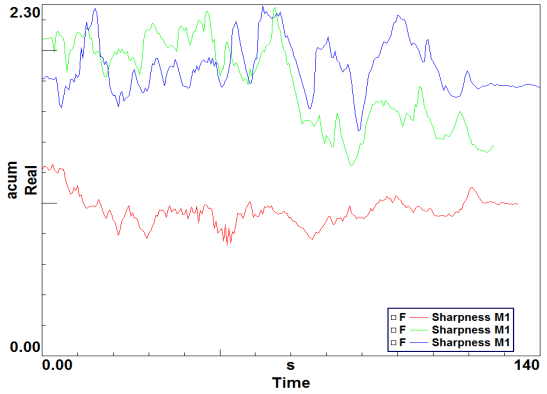
0%
6%
49%

Tonality



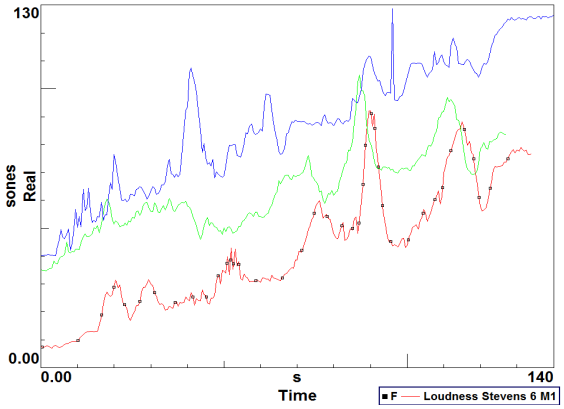
49%
0%
-49%





0%
6%
49%

Sharpness



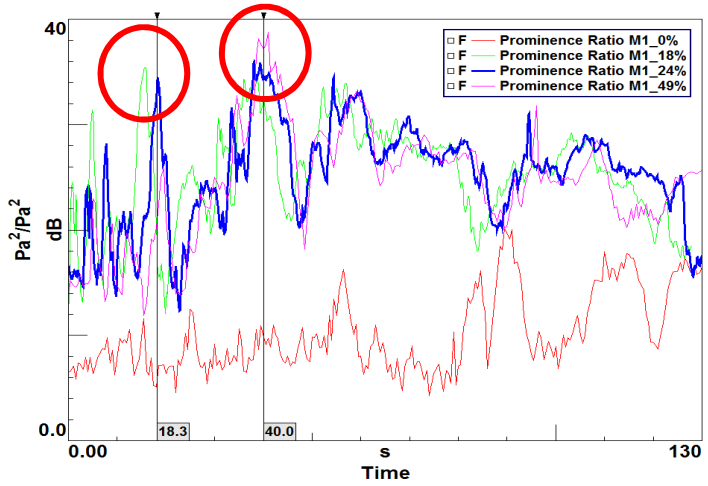
0%
6%
49%

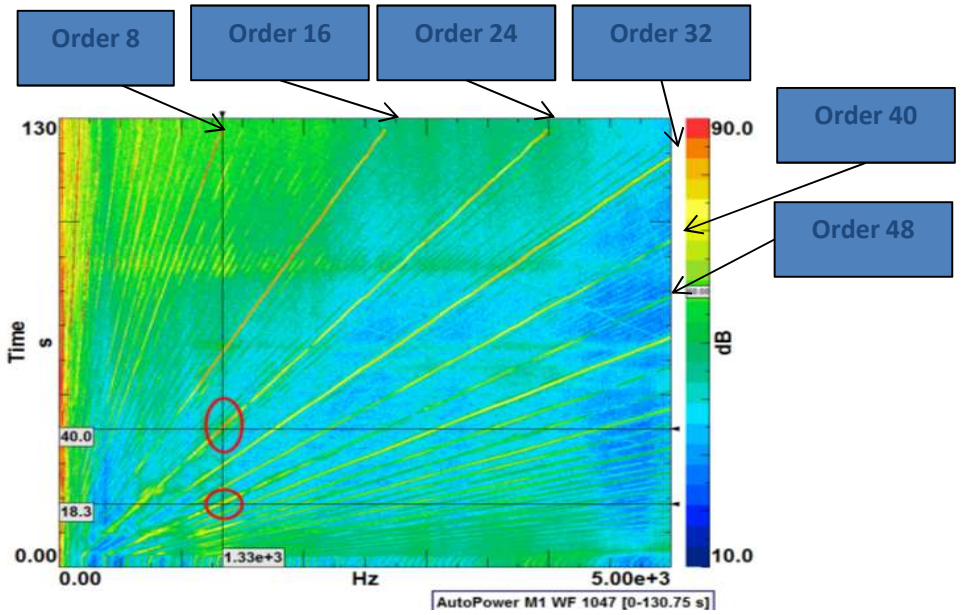
Loudness

Organized by Hosted by In collaboration with Supported by

Sound Quality Evaluation

Prominence ratio:





Prominence ratio is a metric related to the detection and evaluation of prominent discrete tones in noises emissions. In the Prominence ratio method, a discrete tone candidate is said prominent if the average SPL of the "critical band" centered on the tone is at least 9dB higher than the average SPL of the adjacent critical bands.

Conclusion

- The **theoretical assumption** that the ovalization mode is **not** excited in 12/8 configuration could **not** be confirmed with measurements. **Not only the square mode, but also the ovalization mode is excited during run-ups**:
  - Square mode dominates in acceleration signals
  - Ovalization mode dominates in microphone signals !

- Subjective sound evaluation metrics confirm the high **tonality** of the SRM

- **Order 8 with his harmonics** are excited in 12/8 SRM configuration due to the geometry of the rotor and phase excitation principle
  - Order 24 is dominant in the sound (ovalization mode)
  - Order 40 and 56 in the accelerations (square-mode)

Finally, all these NVH tools can help automotive engineers to obtain insight in the vibro-acoustic behavior of electric machines to optimize significant NVH motor characteristics

Additional information

Acknowledgements:

The presented research was achieved in the context of the Flemish research project “SRMOTIF” supported by the IWT Vlaanderen and FP7/2012-2015 research project “ASTERICS”.

http://www.asterics-project.eu/
http://www.green-cars-initiative.eu/projects/asterics

Asterics

Ageing and efficiency Simulation & TEsting under Real world conditions for Innovative electric vehicle Components and Systems

Organized by Fira Barcelona avele

Hosted by AVERE mea Ajuntament de Barcelona

In collaboration with EVAAP EDTA

Supported by European Commission

Questions and answers



LMS®
A Siemens Business

Thank you very much for your attention

Mathieu.sarrazin@lmsintl.com

Organized by Fira Barcelona avele

Hosted by AVERE mea Ajuntament de Barcelona

In collaboration with EVAAP EDTA

Supported by European Commission