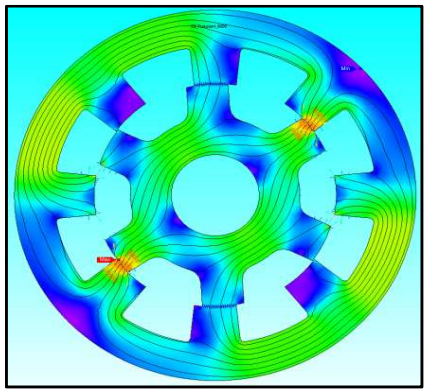
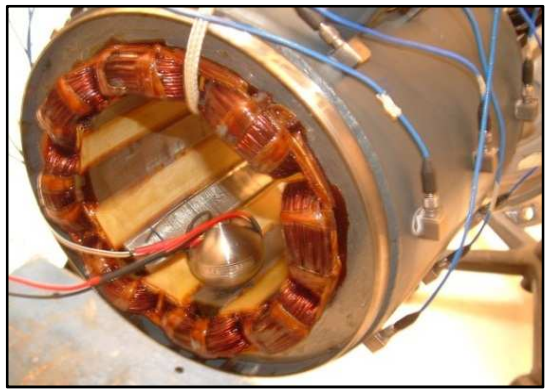
evs 27

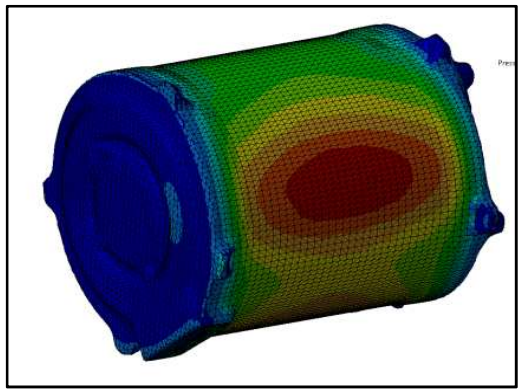
The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.

Barcelona, Spain
17th-20th November 2013

CAE Based Noise Optimization of a Switched Reluctance Electric Motor for Automotive Propulsion Applications







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Saphir Faid, Diederik Brems, Fabrice Boon – Punch Powertrain N.V

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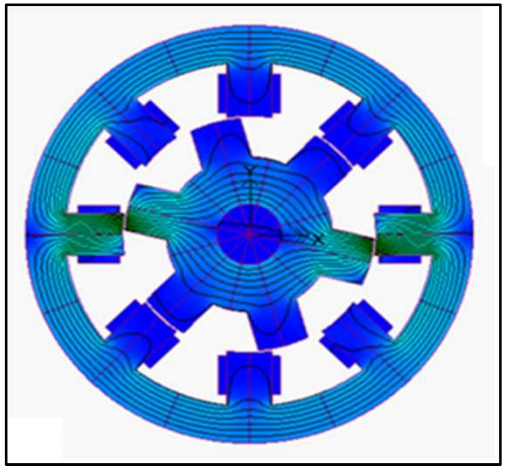
Noise optimization of an SR electric motor

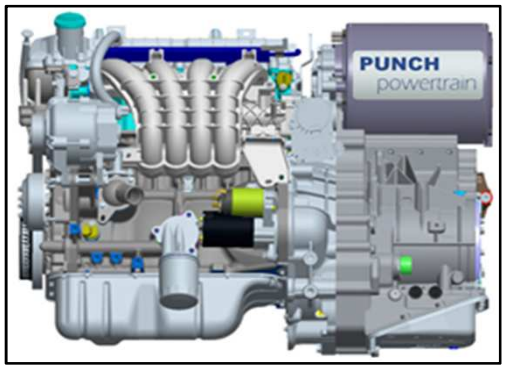
Introduction

- Electric motors are key to all electric and hybrid-electric automotive propulsion solutions.

- Main advantage of Switched Reluctance (SR) type electric motors
  - Cost-effective technology, simple construction
  - No rare-earth materials (permanent magnets)
  - No electric or magnetic components in rotor

- Main drawback in automotive applications
  - Control for maximum efficiency leads to high torque ripple
  - High torque ripple creates NVH problems.



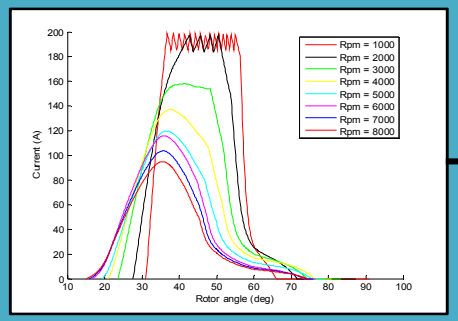


Noise optimization of an SR electric motor

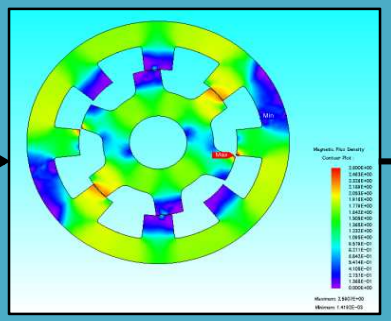
Overview

1 Electro-Magnetic

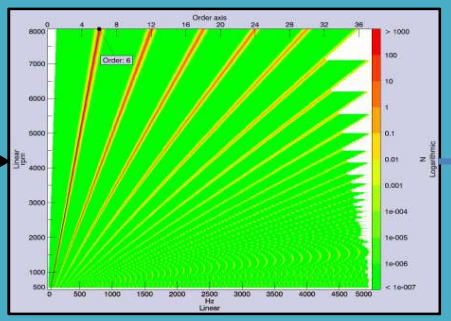
Current waveforms



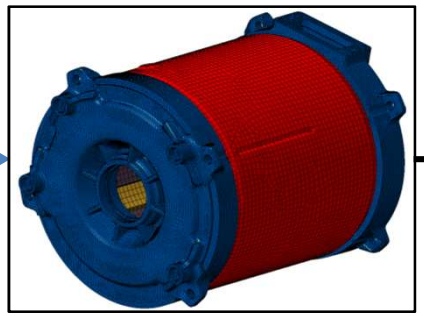
Electro-magnetic FEM



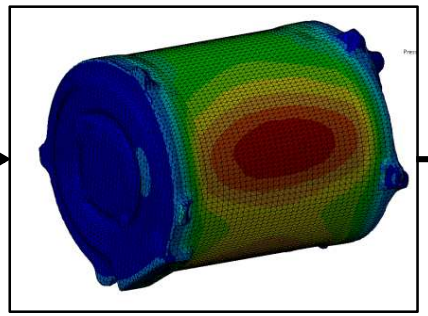
Stator Forces



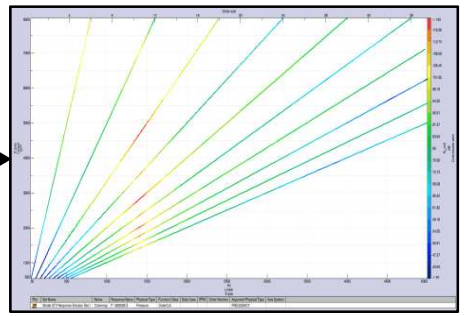
2 Vibro-Acoustic



Structural FEM



Stator Deformation



Radiated Noise

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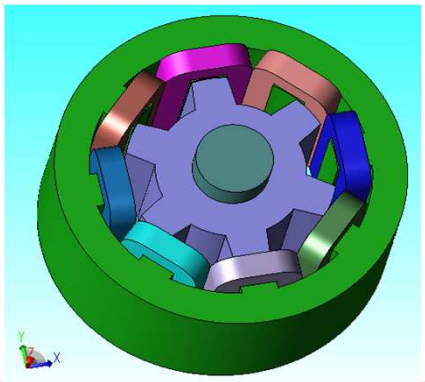
Noise optimization of an SR electric motor

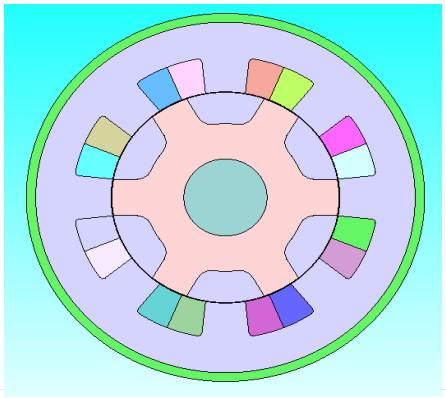
Electromagnetic Simulation

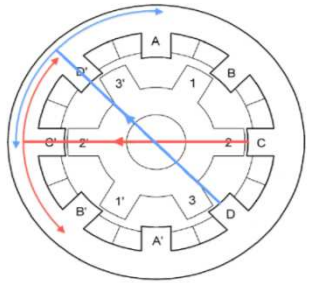
- 2D Electro-Magnetic FE-model (stator, rotor, windings)
- Time domain simulation based on current waveforms for 60º rotor rotation
  - For motor and generator mode
  - For rpms from 525 rpm to 8.000 rpm
  - Only 60º of rotation are computed
  - Full 360º electro-magnetic FE modeled is calculated
  - Maximum frequency of interest: 5000 Hz (sampling frequency of 50000 Hz)
  - Minimum frequency for each rpm is the 6th order frequency

3D FE model

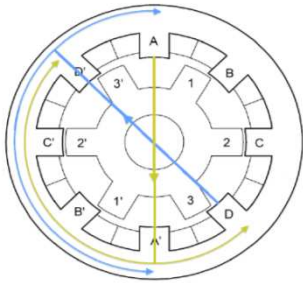


2D FE model

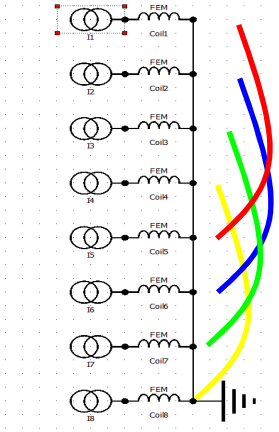




(a)Between stator poles C' and D'



(b)Between stator poles A' and D'



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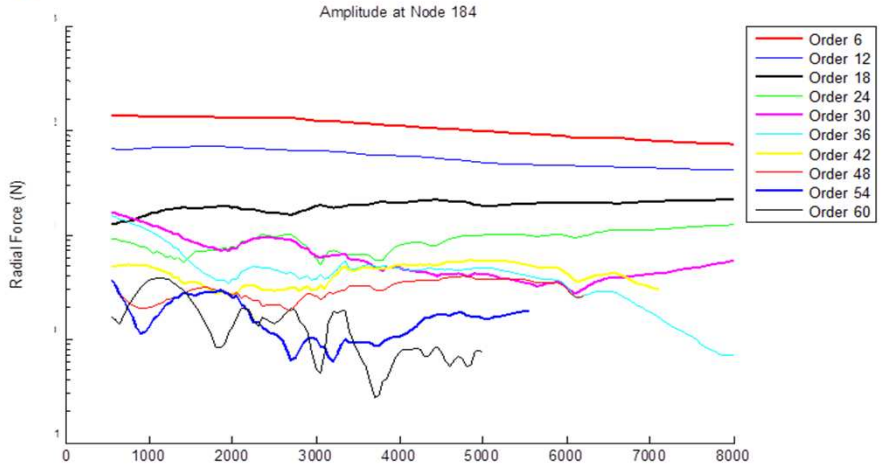
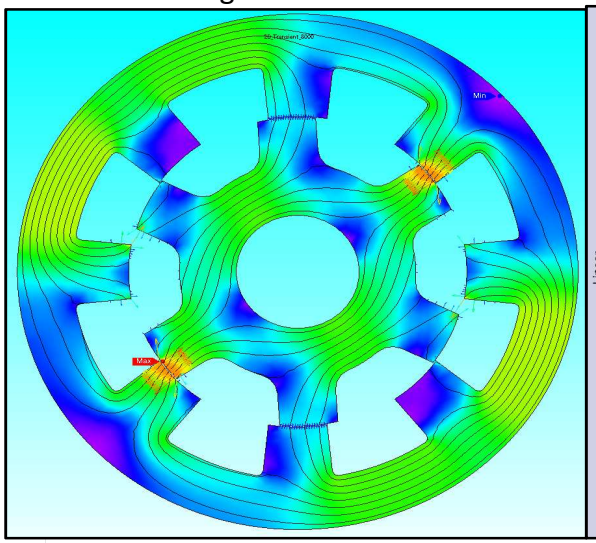
Noise optimization of an SR electric motor

Electromagnetic Simulation

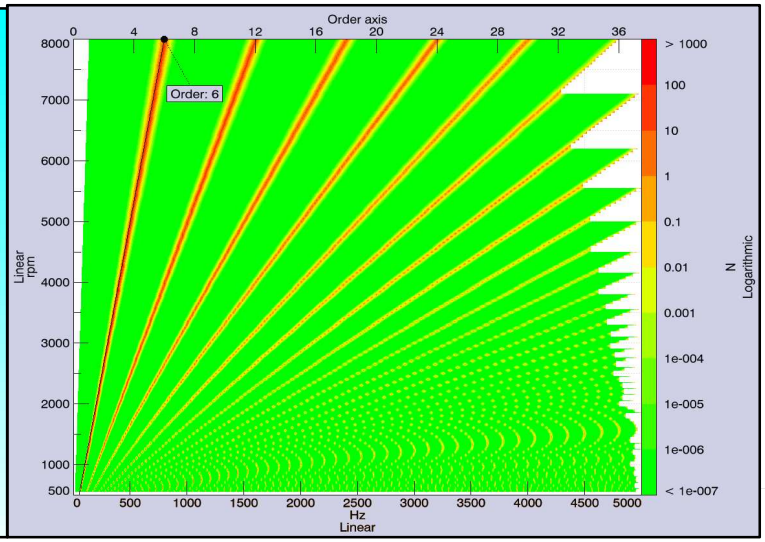
- Results
  - High tangential forces between rotor and stator (motor torque)
  - Radial forces more likely to cause noise
  - The top orders have smooth, continuous lines



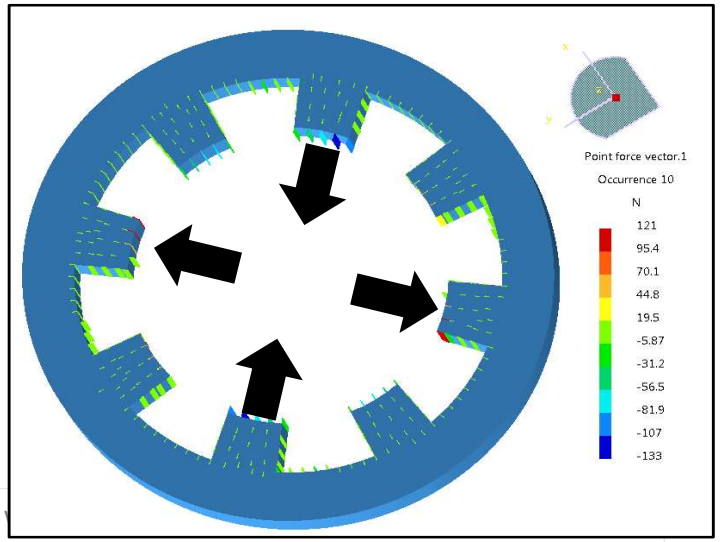
Magnetic flux lines



Stator forces



Force pattern for order 6,18,…

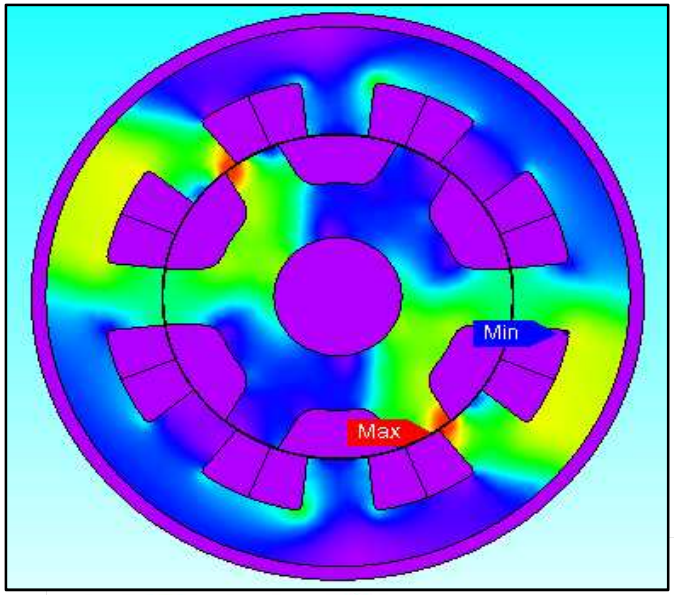


Noise optimization of an SR electric motor

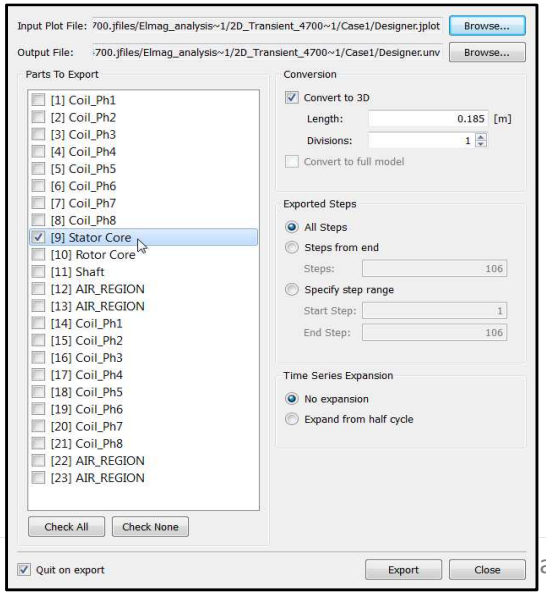
Mapping EM Forces

- JMAG: Export to VL functionality: Export of forces on stator surface in time domain and extrusion from 2D to 3D model
- LMS Virtual.Lab Acoustics:
  - Conservative mapping from EM mesh onto structural model mesh
  - Conversion from time to frequency domain

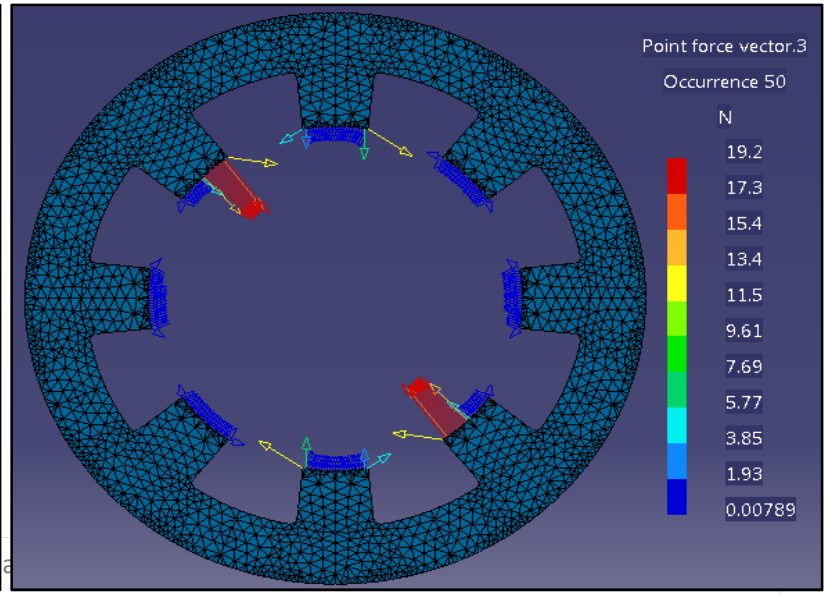
Magnetic Flux Density in JMAG



Force Export to LMS Virtual.Lab



Forces on SRM stator in LMS Virtual.Lab



Noise optimization of an SR electric motor

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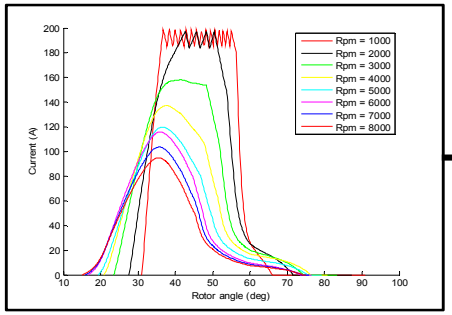
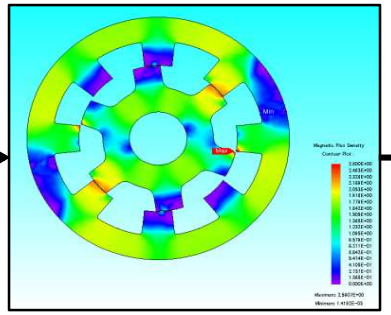
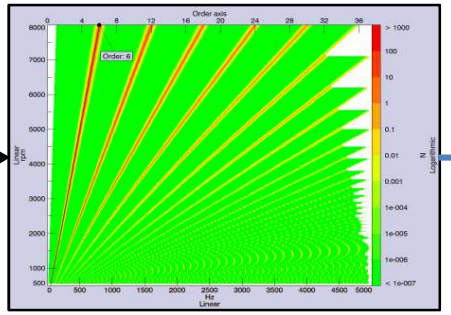


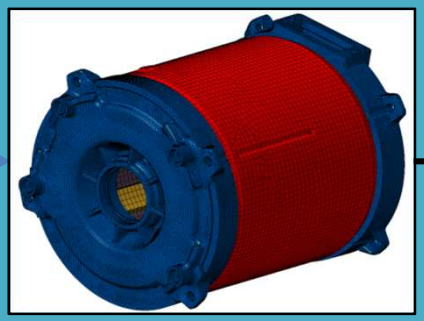
Electro-magnetic FEM



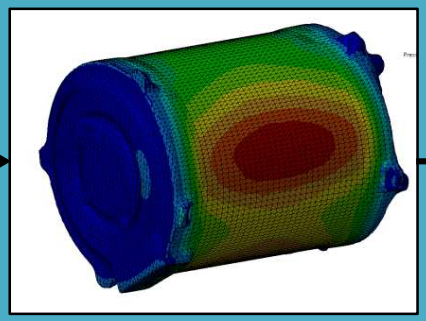
Stator Forces



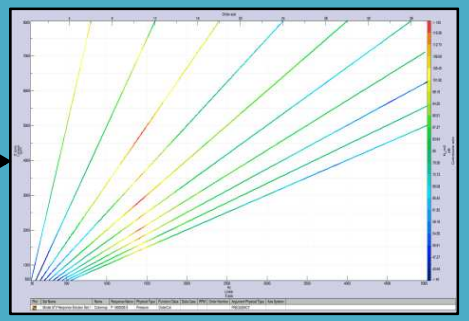
2 Vibro-Acoustic



Structural FEM



Stator Deformation



Radiated Noise

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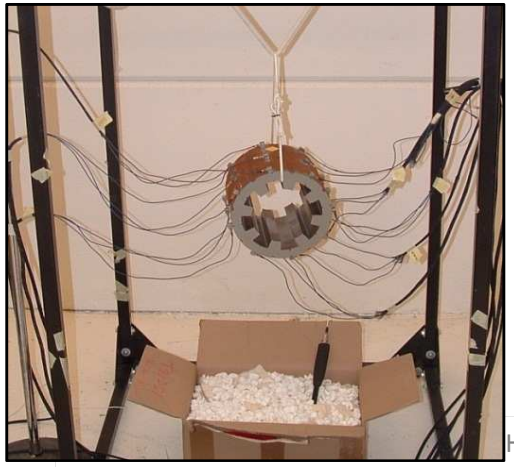
Noise optimization of an SR electric motor

Structural Model

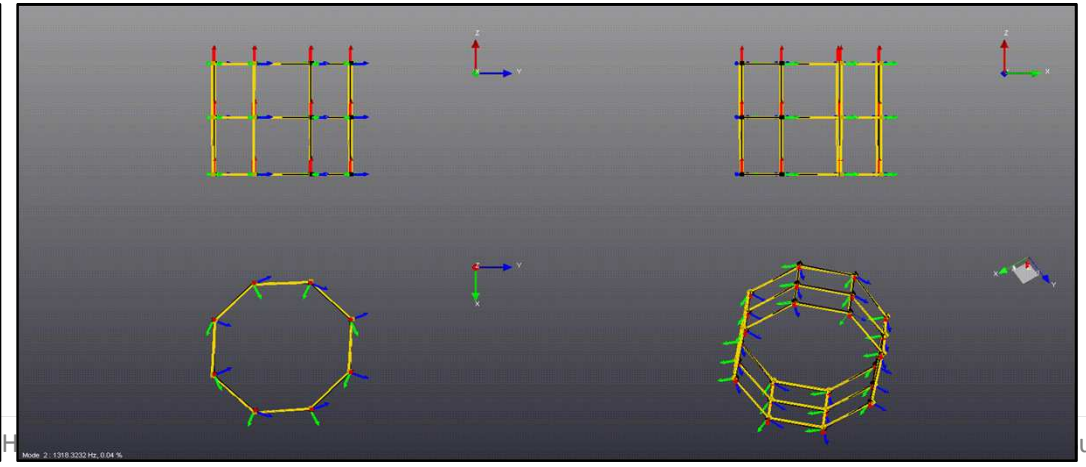
- Stator modelling
  - Stator FRFs testing
  - Stator Modal analysis
  - Stator modelling with anisotropic material properties
  - Correlation and updating to identify properties
- Highest focus on ovalisation modes
  - Good match with forcing pattern
  - Efficient radiator

Mode	TEST	CAE		Description
	Freq [Hz]	Freq [Hz] original	Freq [Hz] updated	
2,½	1255			
2,0a	1318	1293	1319	1st ovalisation
2,0b	1342	1295	1343	1st ovalisation (45 deg)
2,1	1632			
3,0	3527	3426	3526	3rd ovalisation
4,0	5745	5541	5701	4th ovalisation

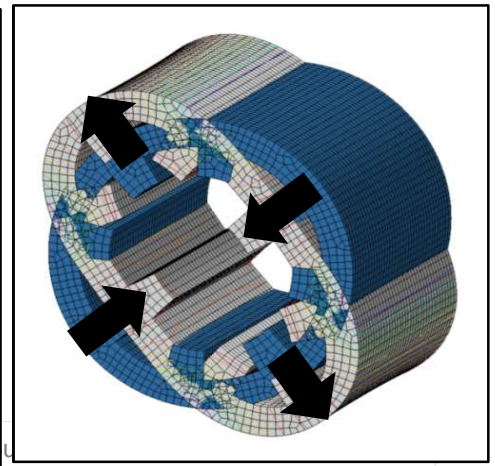
Stator FRF test



Stator TEST modes



Stator CAE modes



Noise optimization of an SR electric motor

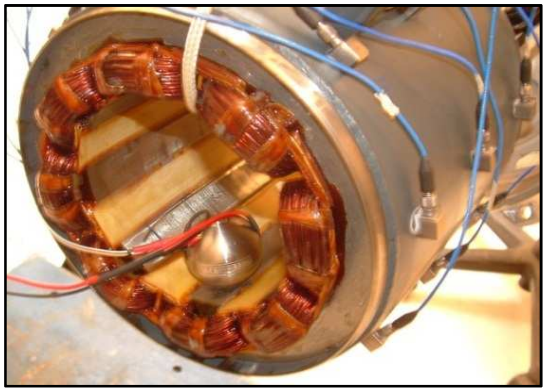
Structural Model

- Completion to full assembly
  - Windings
  - Housing (cooling jacket)
  - Effect of cooling water
  - End caps (covers)

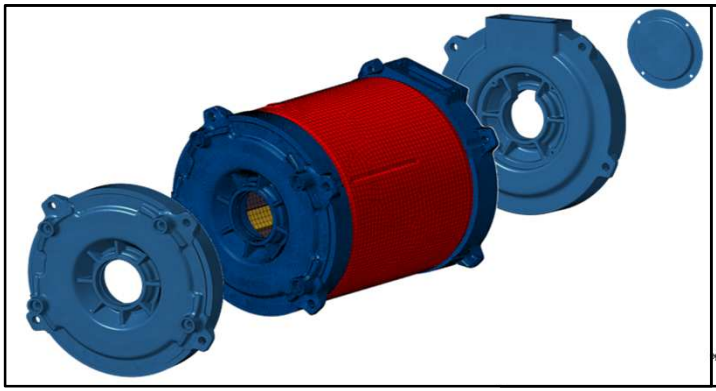
- Step by step correlation with measurement data

Mode	TEST Freq [Hz]	CAE Freq [Hz]	Description
2,0a	1414	1400	1st ovalisation
2,0b	1434	1412	1st ovalisation (45 deg)

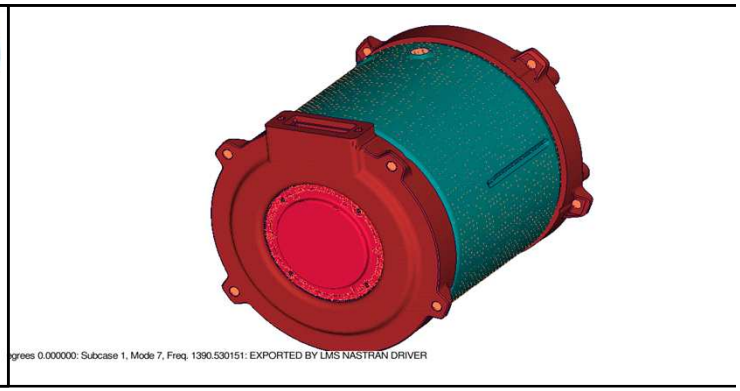
Assembly FRF test



Assembly Model



Assembly Mode

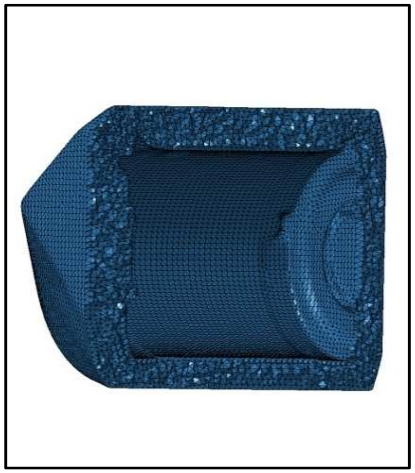


Noise optimization of an SR electric motor

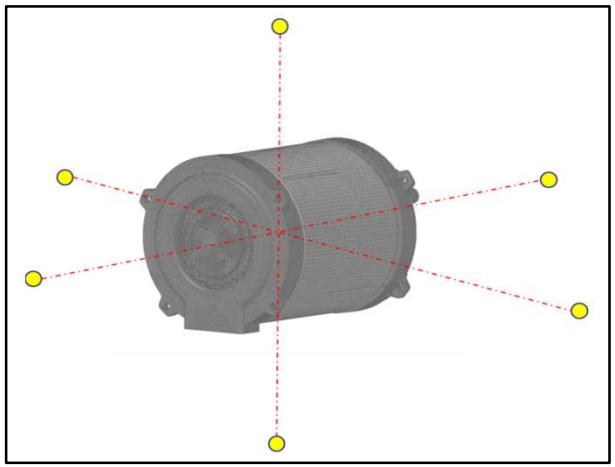
Vibro-Acoustic Forced Response

- Structural Forced Response → surface vibrations for main motor orders (6,12,…)
- Creation of Acoustic model
  - Wrap of the structural model with free-field termination at boundary
  - 6 field microphones @ 1 m
- Calculation of pressure in field points resulting from surface vibrations

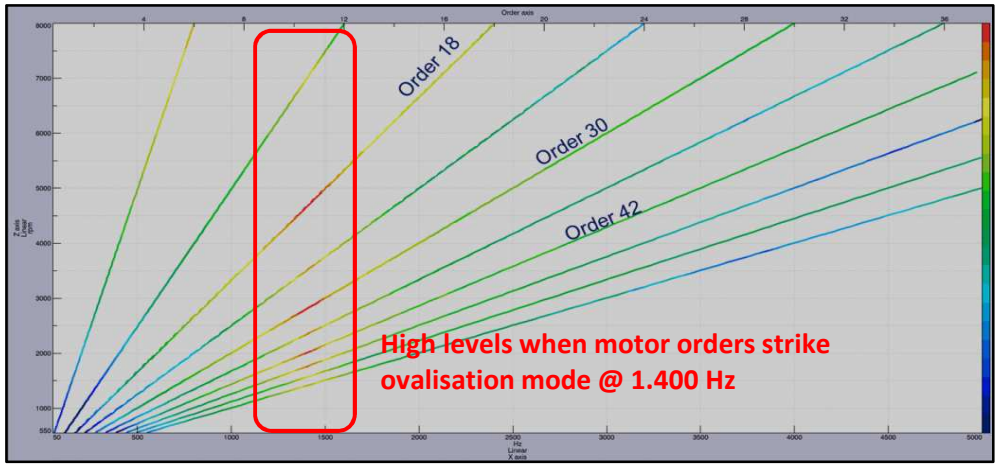
Acoustic model



Evaluation microphone positions



Noise at field point



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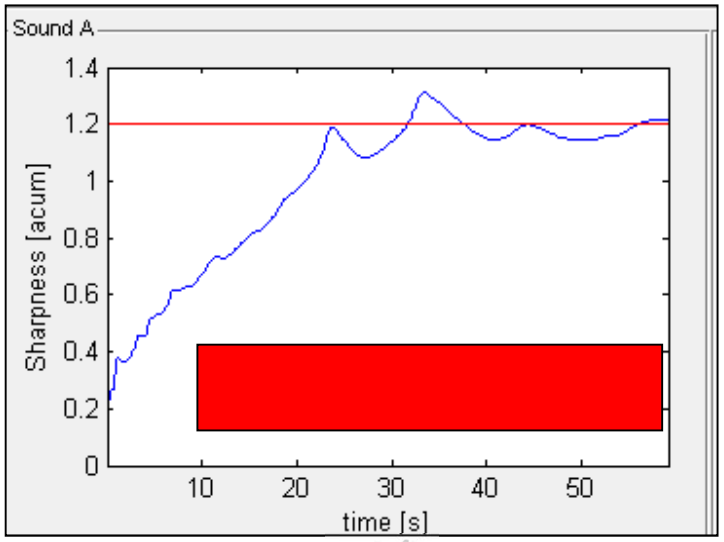
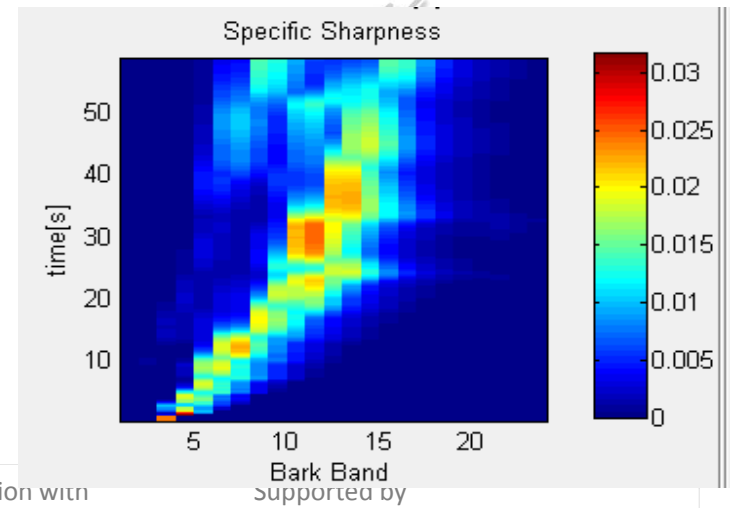
Noise optimization of an SR electric motor

Subjective Evaluation

- Tonal noise is often perceived to be annoying, even when its sound level is not very high.
- Metrics related to level (OA level, dB(A), Loudness) are not appropriate for high frequency pure tone noise
- Dedicated metrics for tonal noise
  - Prominence ratio (*)
  - Tonality (*)
  - Sharpness

  (*) Due to the lack of broad band noise data, not applicable for CAE results
- Sharpness is used to evaluate CAE results



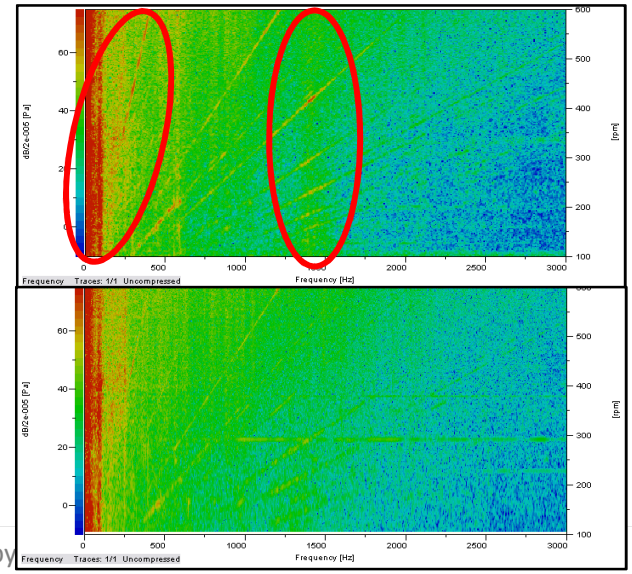


Noise optimization of an SR electric motor

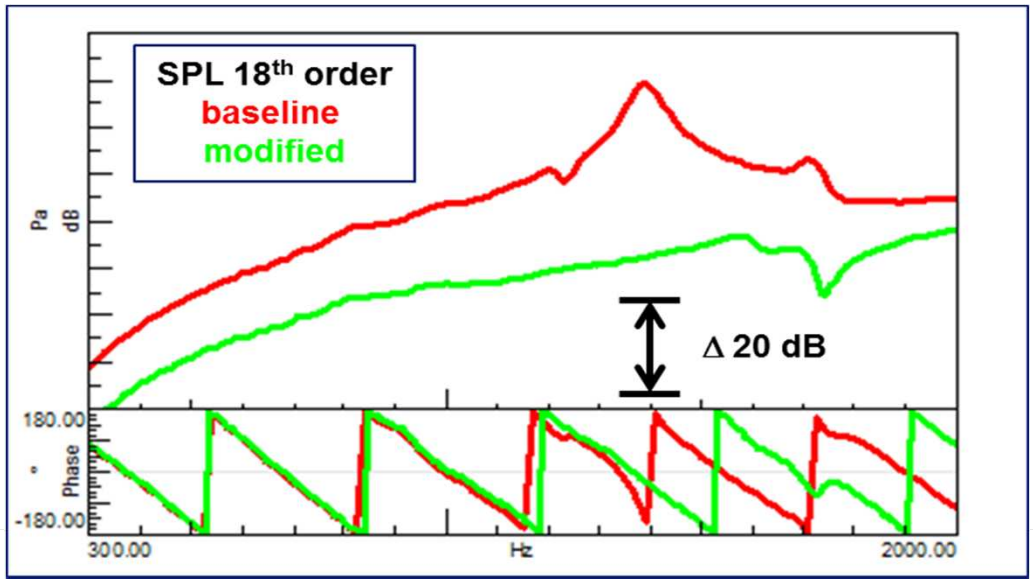
Optimization

- Optimization of the motor control strategy allows to reduce the torque ripple, but can also be used to significantly reduce the noise radiated by the SRM
- Structural optimization of the motor and its housing allows to further reduce the noise radiated by the SR motor.
  - Simulation allows to understand the reasons behind high noise levels in certain rpm-ranges. Noise peaks typically occur when a motor order strikes a structural resonance and the stator force pattern matches well with the mode shape.
  - Design changes can be proposed, typically addressing resonance issues by adding damping to the structural modes.

Effect of Optimized Control Strategy



Effect of Structural Modifications



Noise optimization of an SR electric motor

Conclusions

- Switched Reluctance Motors are an interesting alternative to permanent magnet synchronous motors, but controlling their NVH behavior is a prerequisite to achieve a competitive solution.

- The noise radiation of electric motors can be optimized based on:
  - Electro-magnetic finite element models
    to obtain stator forces starting from current profiles
  - Vibro-acoustic finite element models
    to obtain housing vibrations & noise radiation based on stator forces
    In view of their complex construction (laminates, …), test based validation of the structural models is required

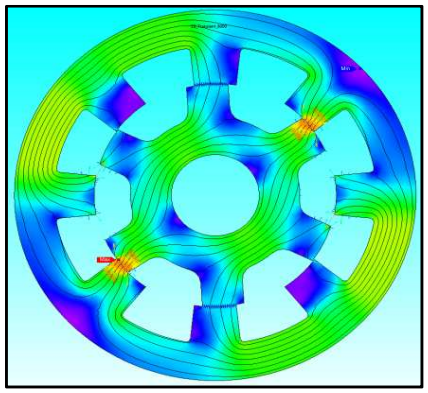
- The process can equally be applied to different motor types (e.g. permanent magnet synchronous motors).

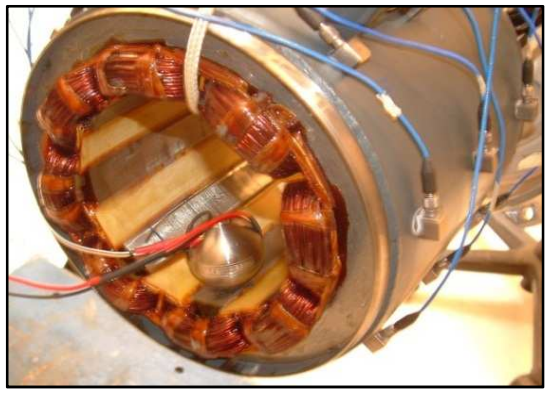
Noise optimization of an SR electric motor

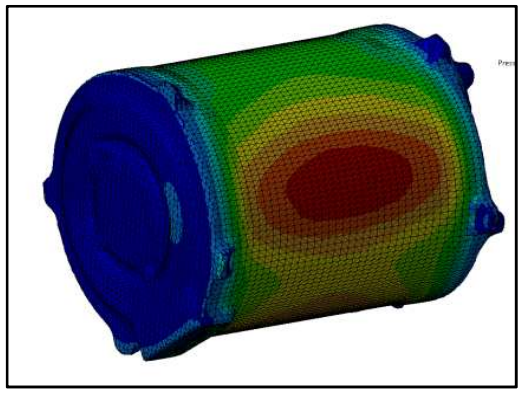
Thank You!

…

Questions?







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