

OR2: A Software Portfolio for NVH optimization of gearboxes

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DI FERRARA
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A Software Portfolio for NVH optimization of gearboxes

Parametric LP model of gearboxes

Gear vibration/variable forces on bearings and casing

Parametric FE model of gearboxes

Natural frequency of casing/ casing vibration

BE model of gearboxes

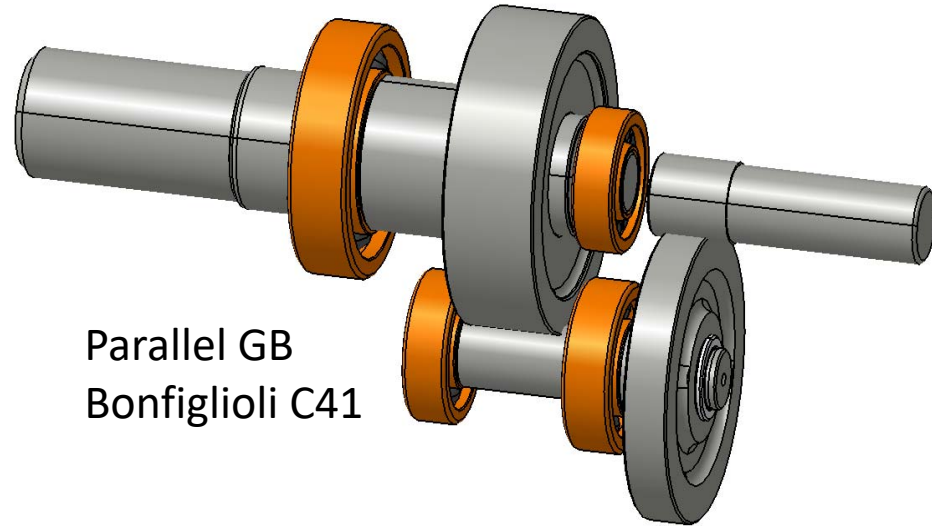
Acoustic radiation

Sound Quality Analysis of gearboxes

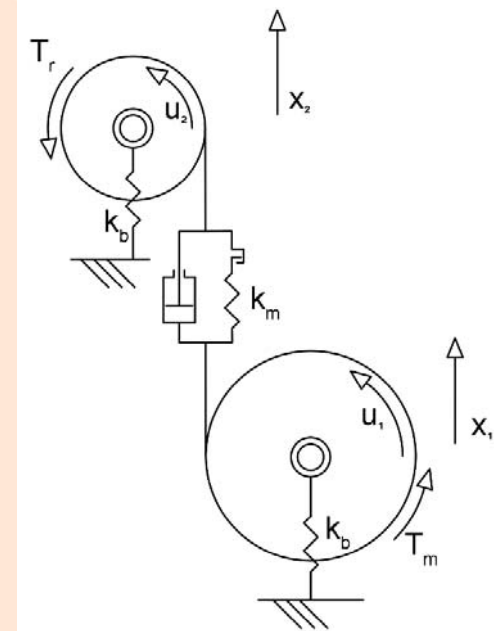
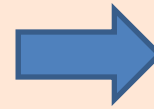
acoustic comfort/metrics

Parametric LP model of gearboxes

> rotating components (gears and shafts)



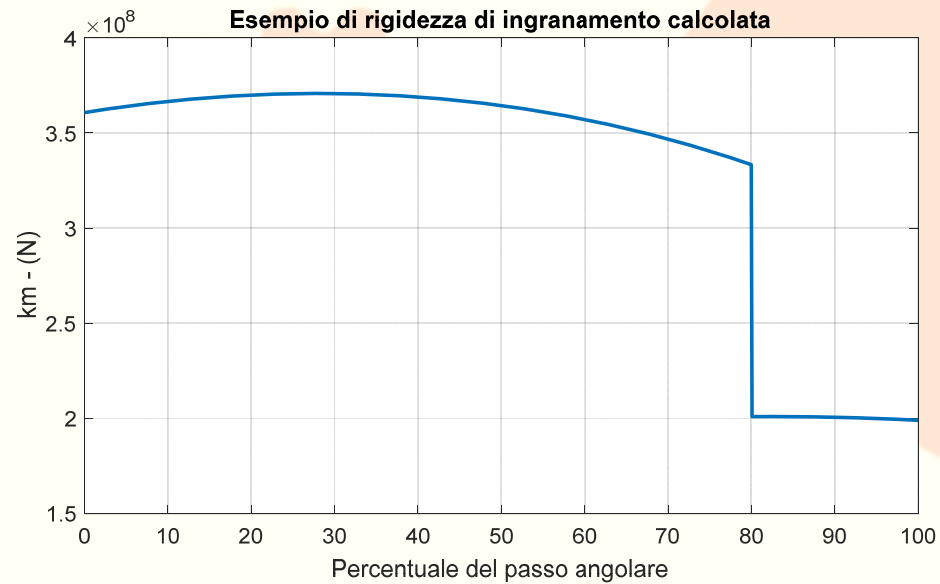
Parallel GB
Bonfiglioli C41



- LP non-linear model
- Low number of DOFs (3 DOFs for each gear)
- Inertia/stiffness/damping
- Variable meshing stiffness
- Profile errors
- Backlash
- Bearing stiffness

Estimation of variable forces
on bearing and casing

Parametric LP model of gearboxes

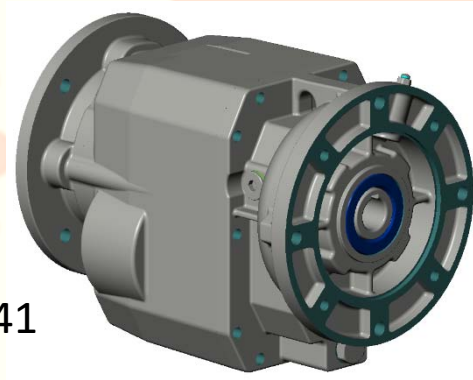


- Linearization of the bearing reaction
- The variable meshing stiffness is evaluated by analytical approaches (e.g. Kuang-Yang)

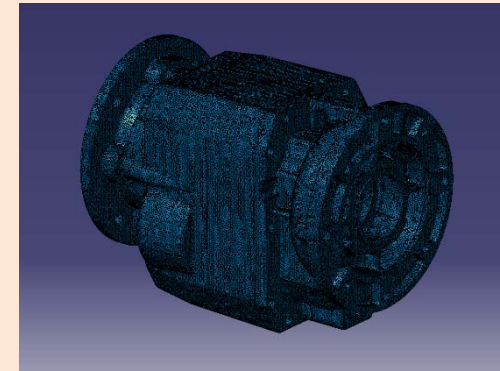
Parametric FE model of gearboxes > casing

Methodology for FE analysis of gearboxes

Parallel GB
Bonfiglioli C41



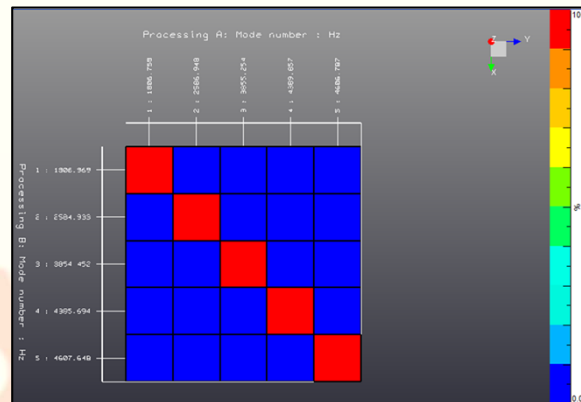
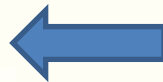
Parametric CAD model



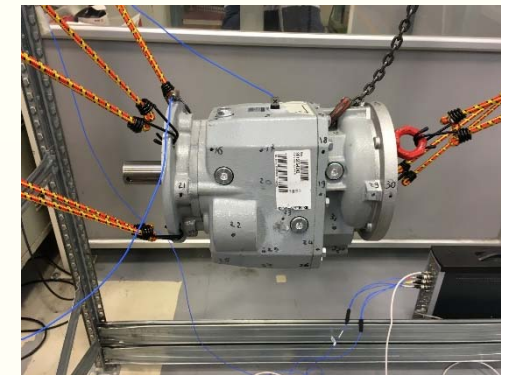
3D FE model



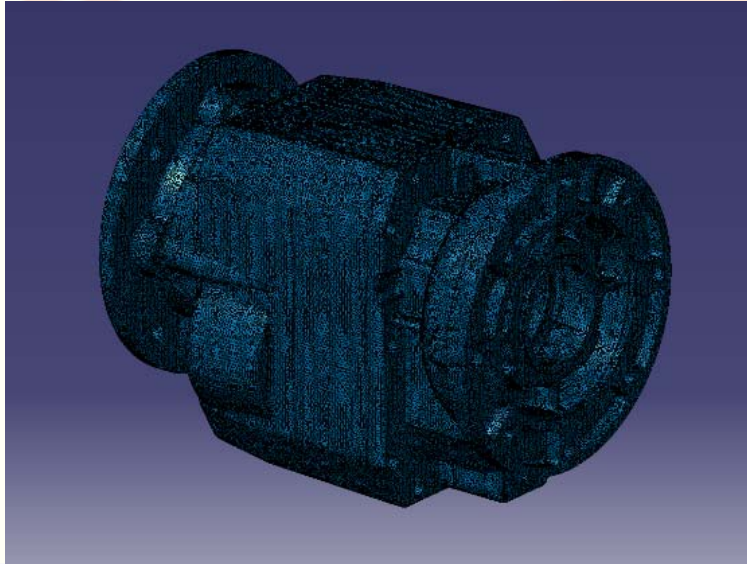
Validated FE model



Experimental validation



Parametric FE model of gearboxes – Modelling



Mesh Dimension:

10 mm

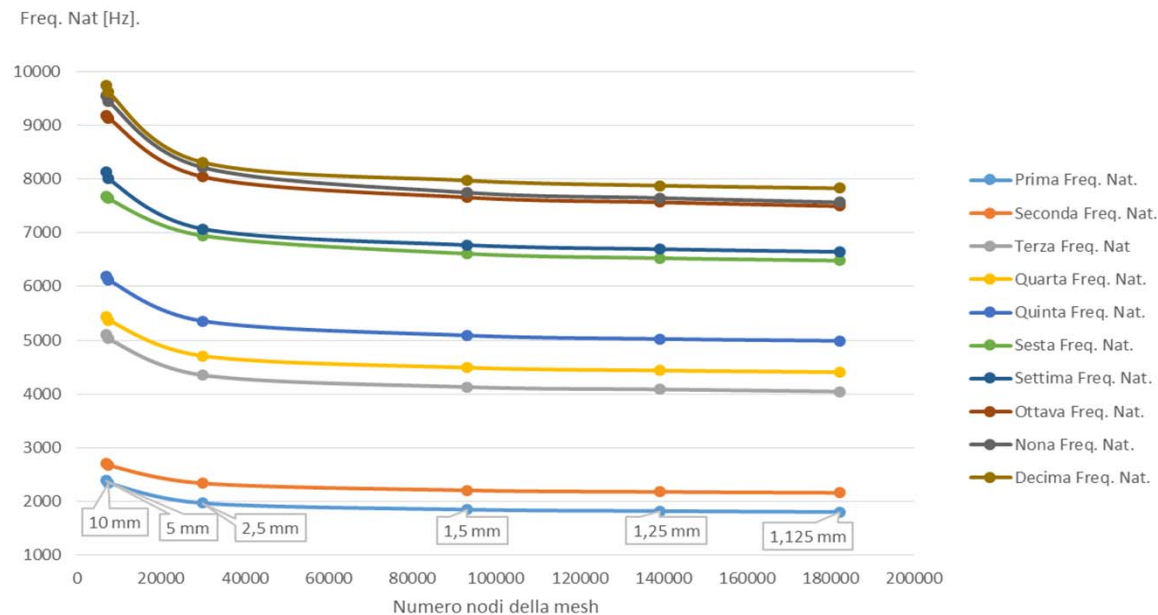
5 mm

2,5 mm

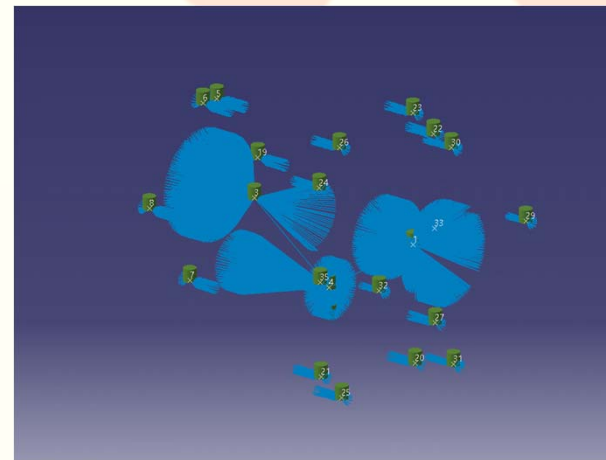
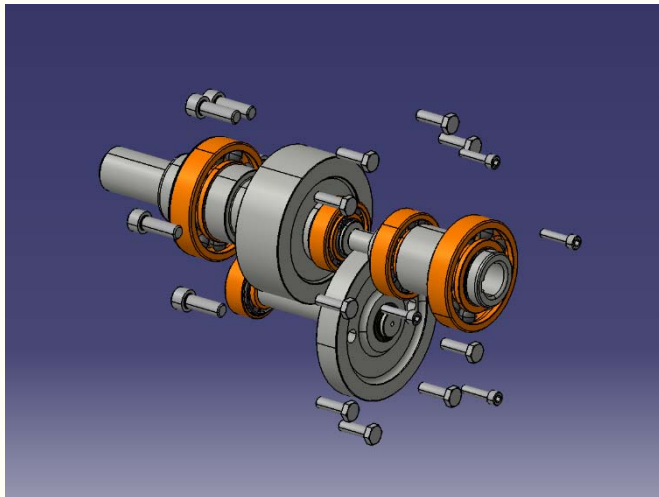
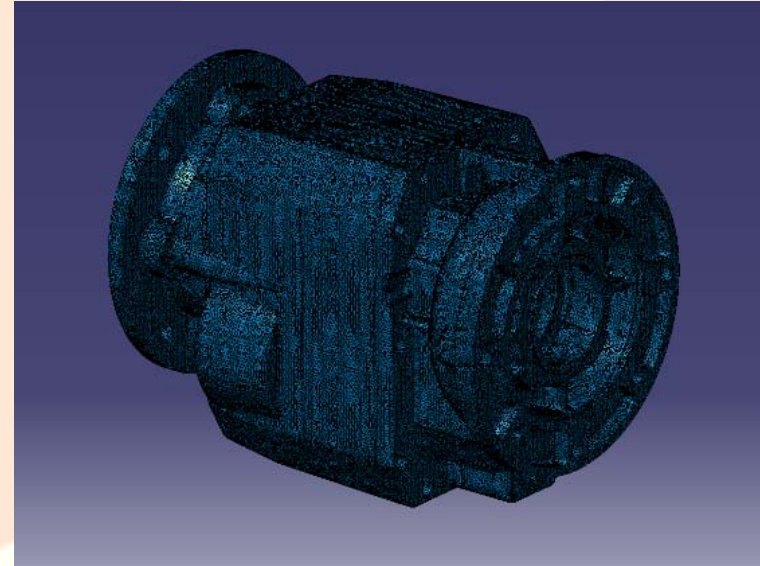
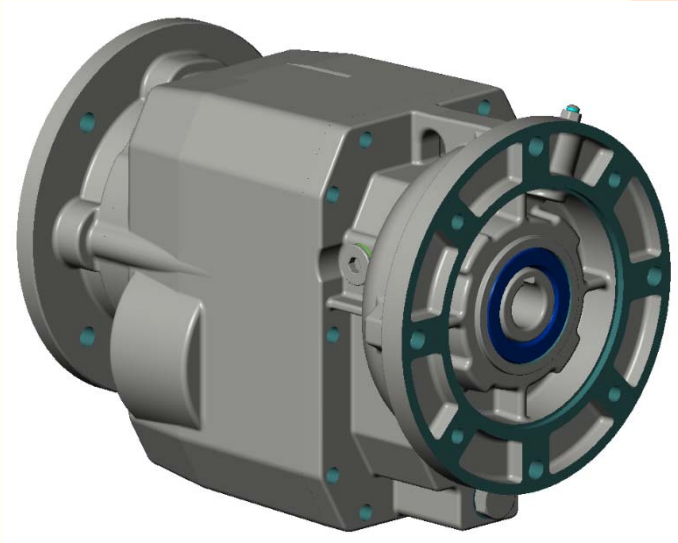
1,5 mm (Err% < 5%)

1,125 mm

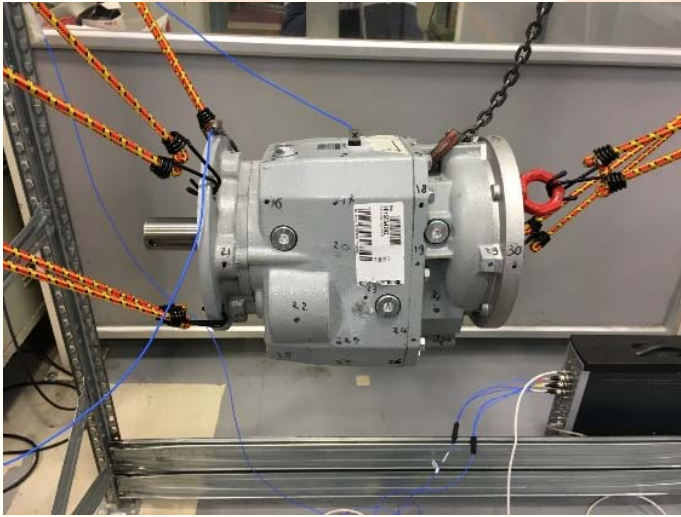
Analisi Convergenza componente 61109000b



Parametric FE model of gearboxes – Modelling



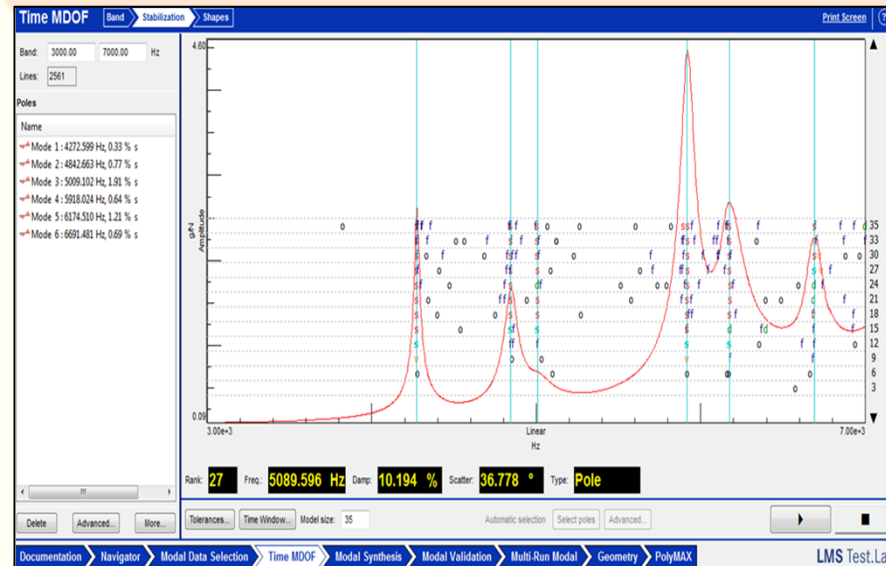
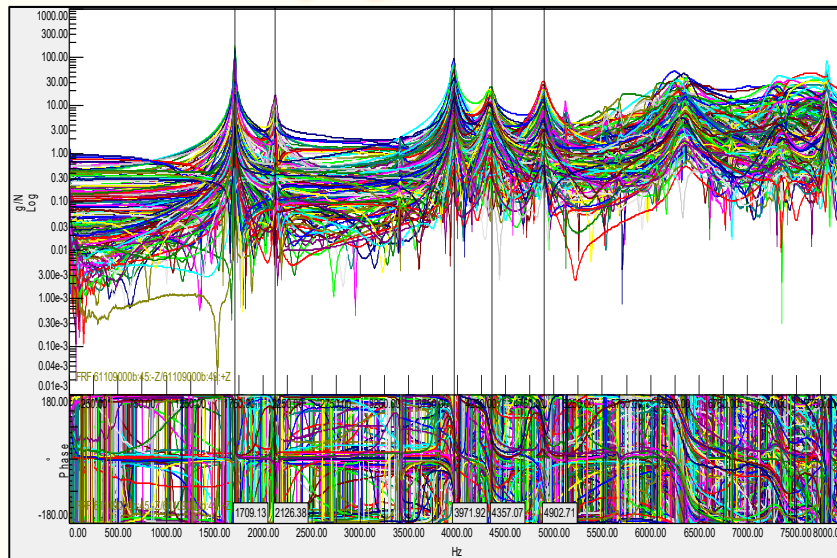
Parametric FE model of gearboxes – Validation



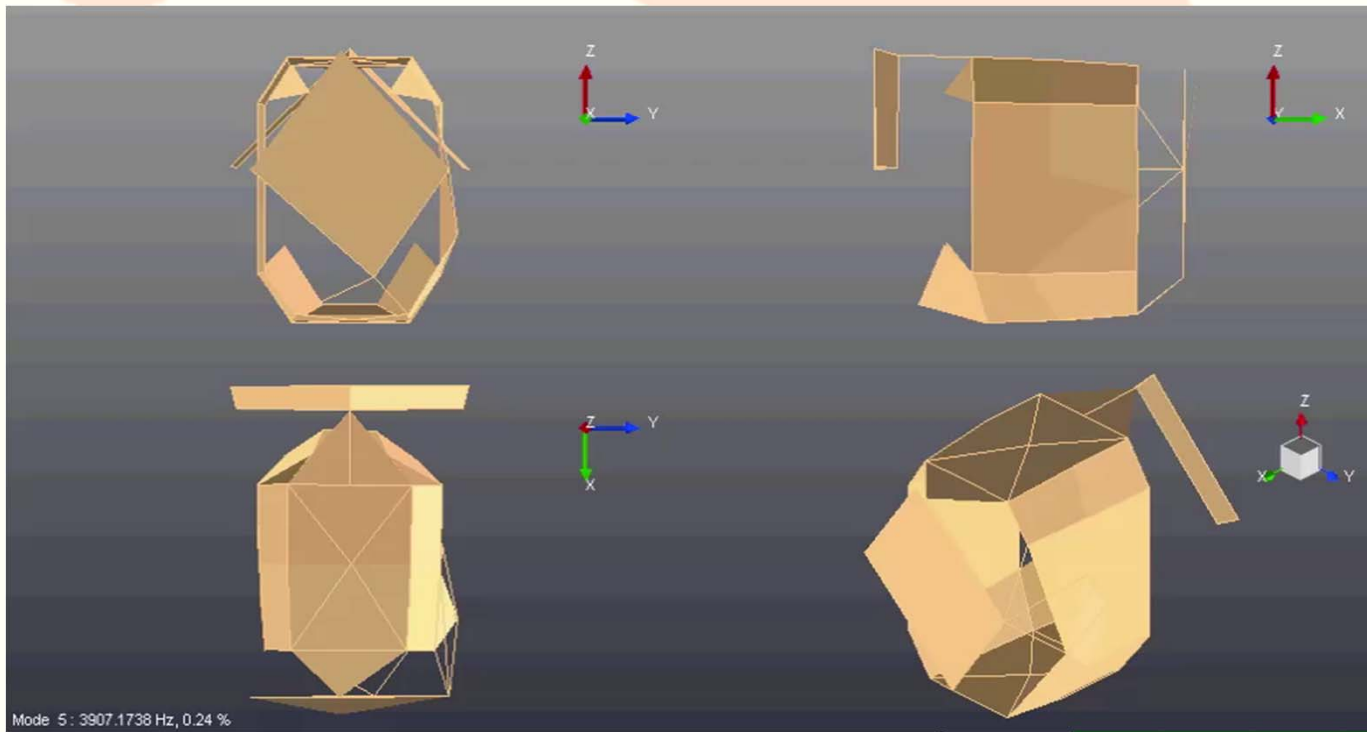
Validation based on
experimental modal analysis



Parametric FE model of gearboxes – Validation



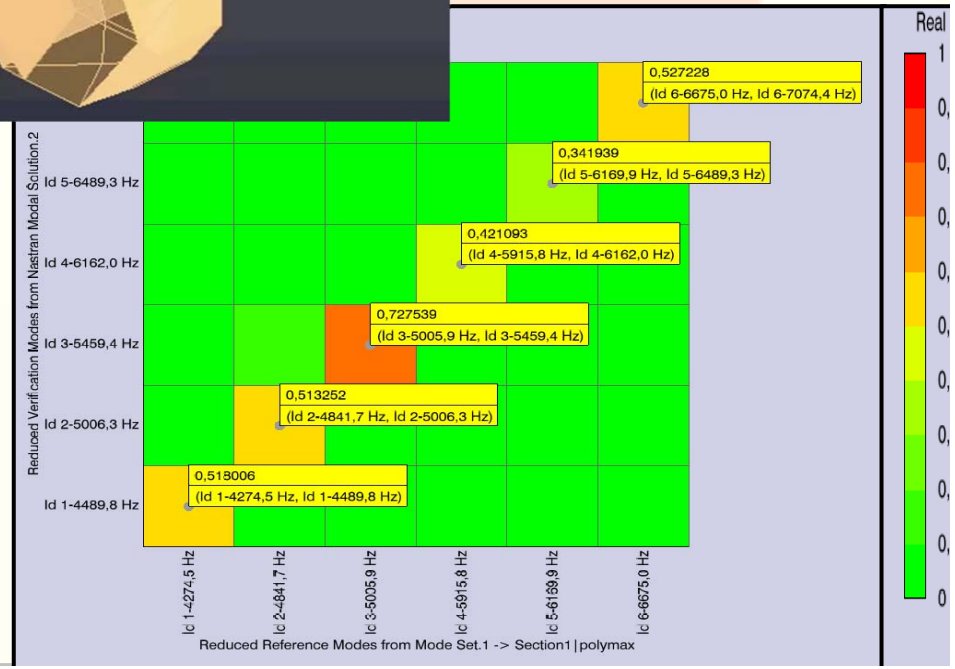
Parametric FE model of gearboxes – Validation



Natural mode shape

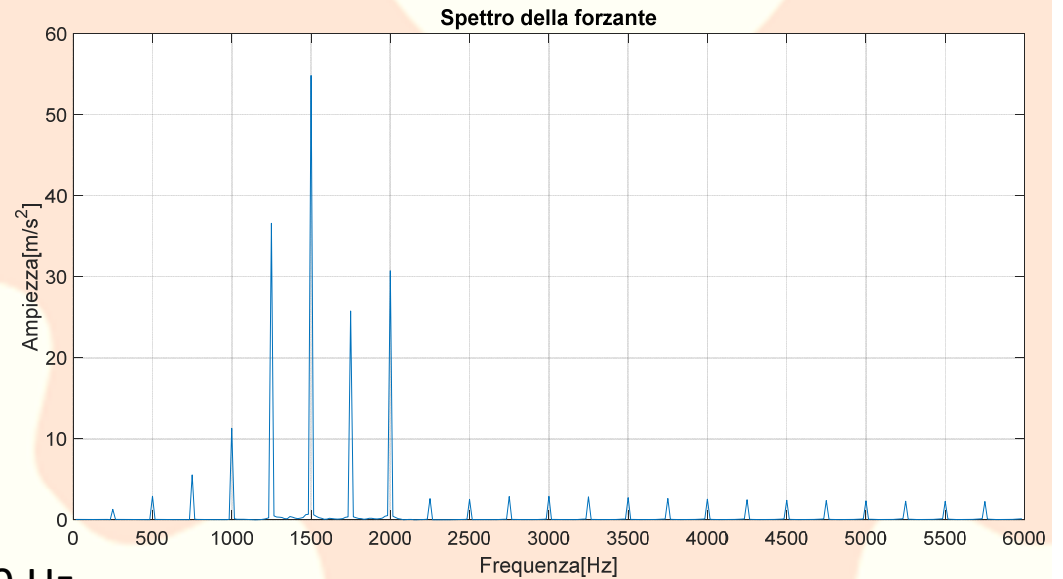
Mode 5: 3907.1738 Hz, 0.24 %

Validation based on MAC on entire gearboxes



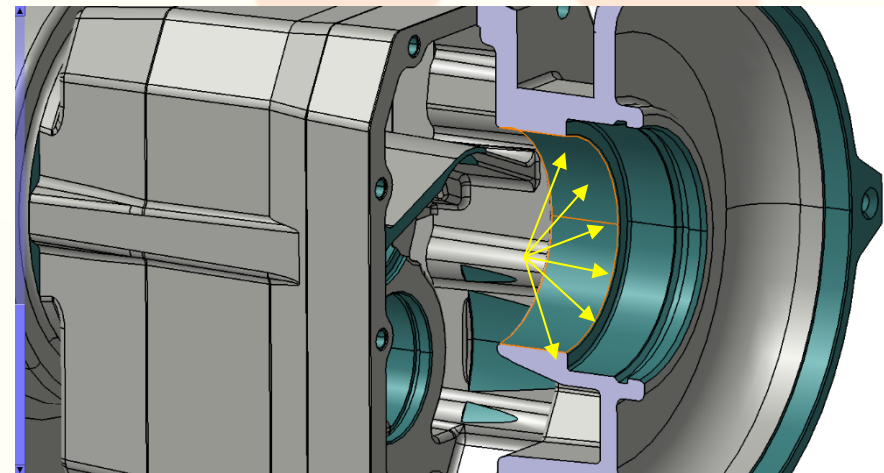
Parametric FE model of gearboxes

Dynamic analysis in operation condition

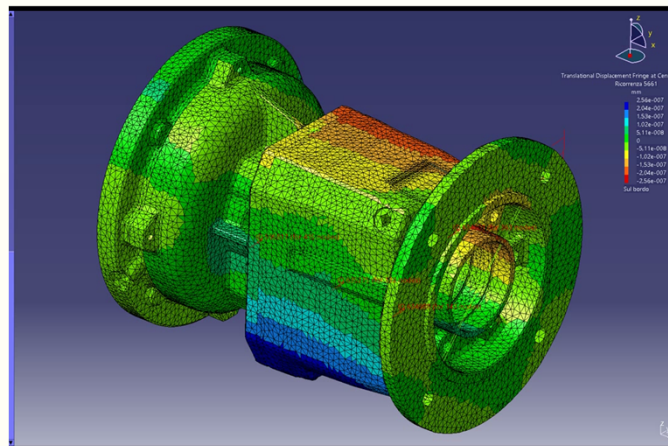
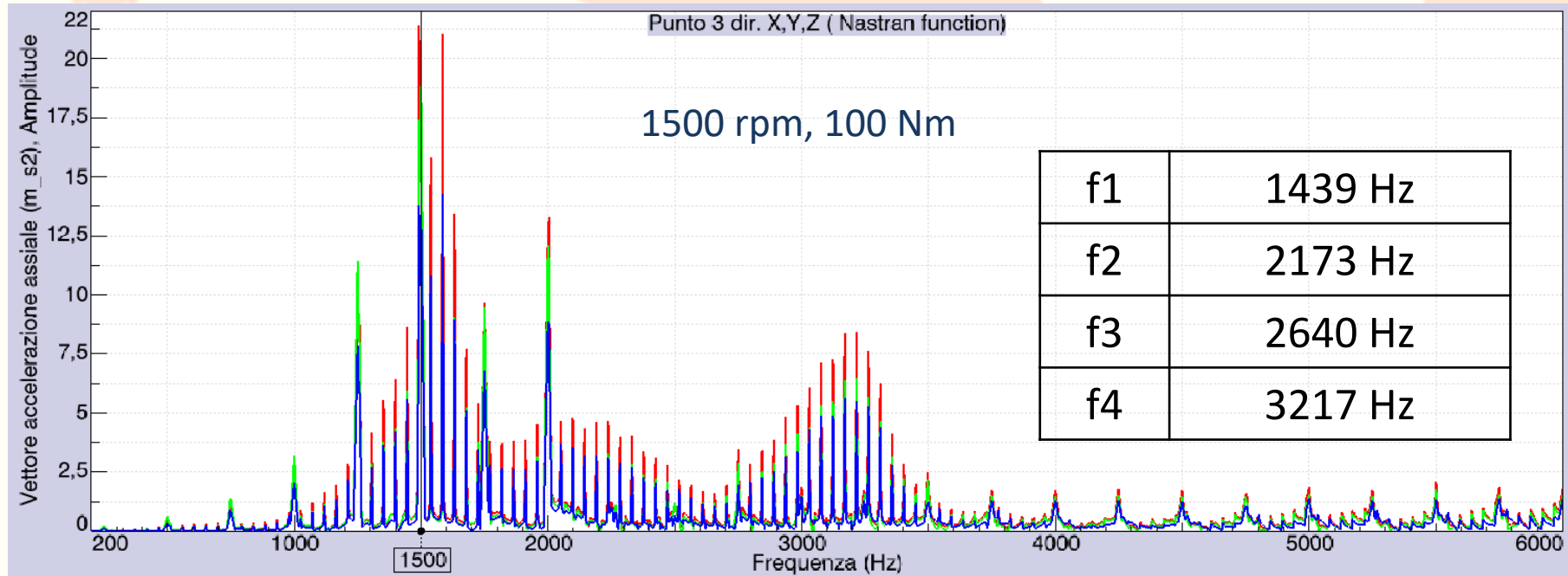


- Dynamic frequency response: 200-6000 Hz, sol 111 (*modal frequency response*)
- Calc. Time: 17 minuti
- Damping obtained from EMA

Nat Freq [Hz]	Modal Damping[%]
1500	1,7
2147	4,5
2706	2
3411	1,3
4170	3,1




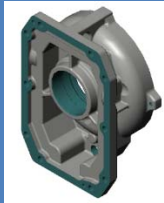
Parametric FE model of gearboxes –Results



3200Hz

Parametric FE model of gearboxes – Application

Sensitivity to dimensional variations within tolerances: MMC and LMC

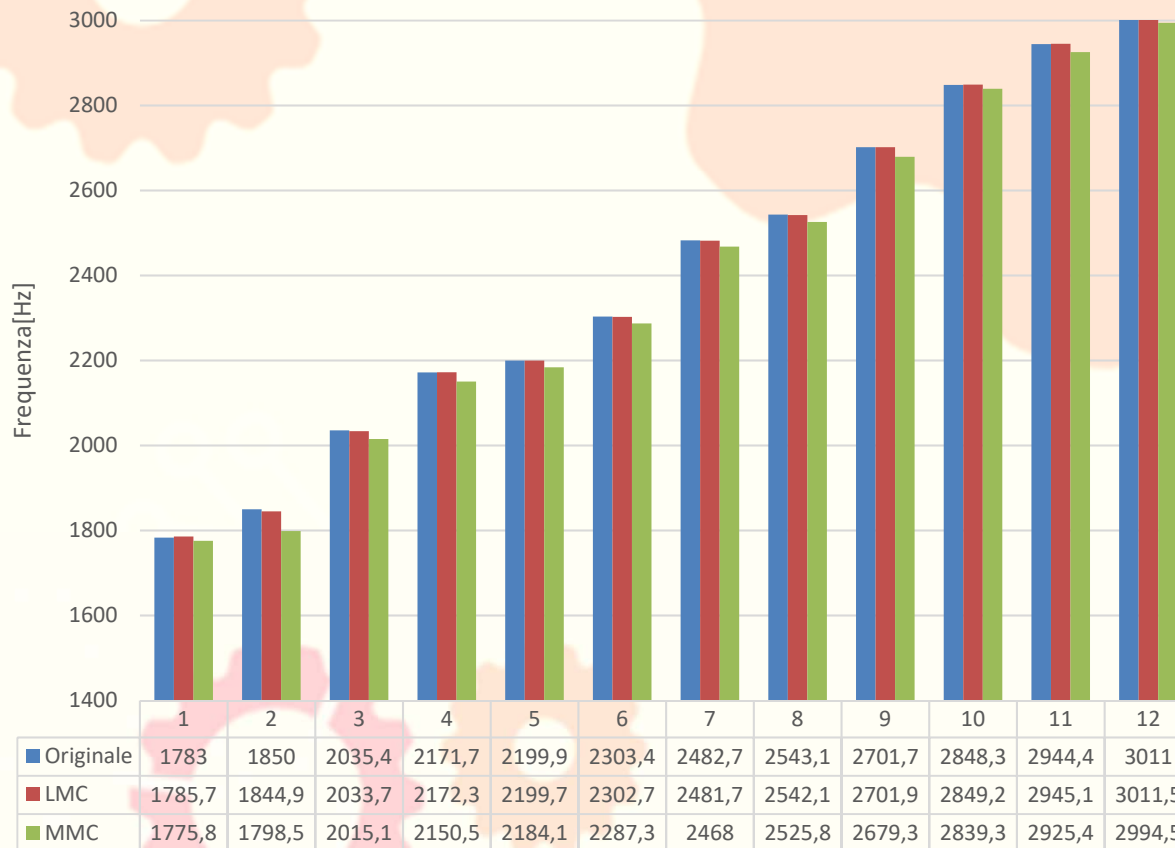
	Standard (da CAD)	LMC	MMC	ΔV	ΔV [%]
	Volume [mm ³]	Volume [mm ³]	Volume [mm ³]	[mm ³]	
 Housing	1,27*10 ⁶	1269954,17	1276598,84	6644,67	0,5
 Cover	566538,96	566540,46	575026,49	8486,03	1,5

Parametric FE model of gearboxes – Application

Modo	Frequenza [Hz]			Δf LMC-MMC [Hz]	Δf [%]
	Standard	LMC	MMC		
1	1783	1785,7	1775,8	9,9	0,6
2	1850	1844,9	1798,5	46,4	2,6
3	2035,4	2033,7	2015,1	18,6	0,9
4	2171,7	2172,3	2150,5	21,8	1,0
5	2199,9	2199,7	2184,1	15,6	0,7
6	2303,4	2302,7	2287,3	15,4	0,7
7	2482,7	2481,7	2468	13,7	0,6
8	2543,1	2542,1	2525,8	16,3	0,6
9	2701,7	2701,9	2679,3	22,6	0,8
10	2848,3	2849,2	2839,3	9,9	0,3
11	2944,4	2945,1	2925,4	19,7	0,7
12	3011	3011,5	2994,5	17,0	0,6

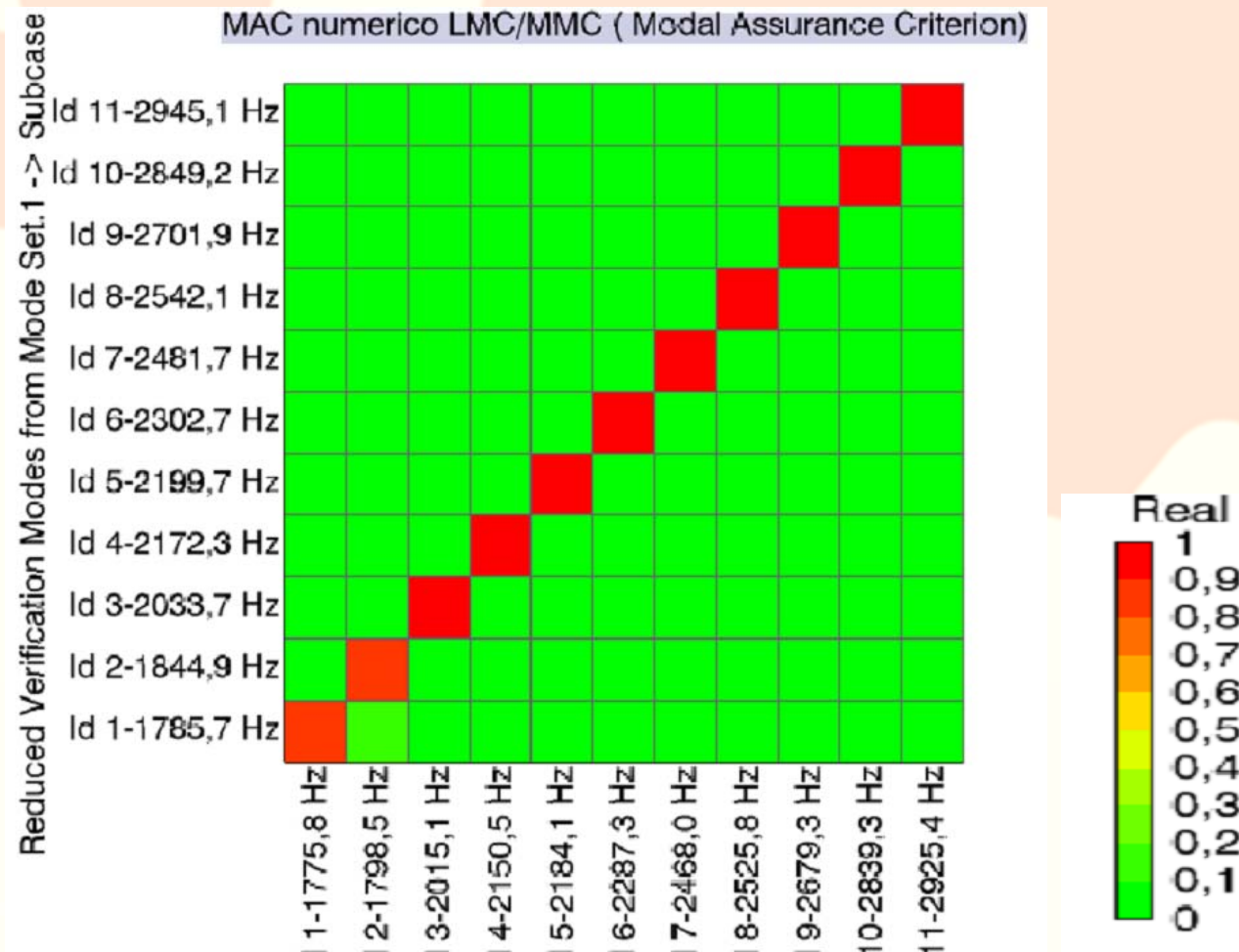
Parametric FE model of gearboxes – Application

- Natural frequency variations are limited: max variation of 2.6% in the 2nd mode.
- The results for LMC are very close to standard conditions.
- Higher differences between MMC and standard conditions.



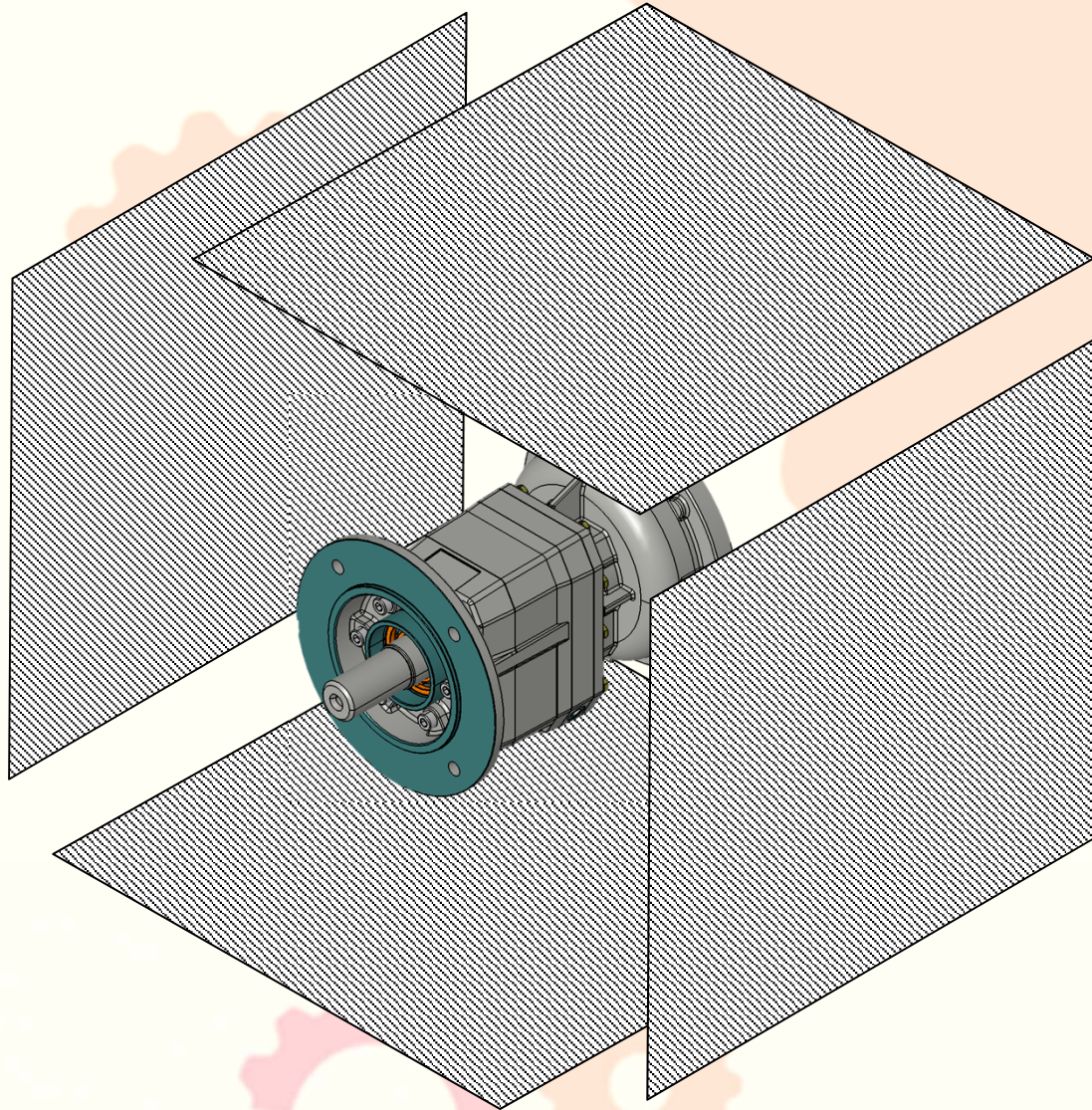
Parametric FE model of gearboxes – Application

- Modal shapes in MMC and LMC are practical identical, as well as in standard condition.

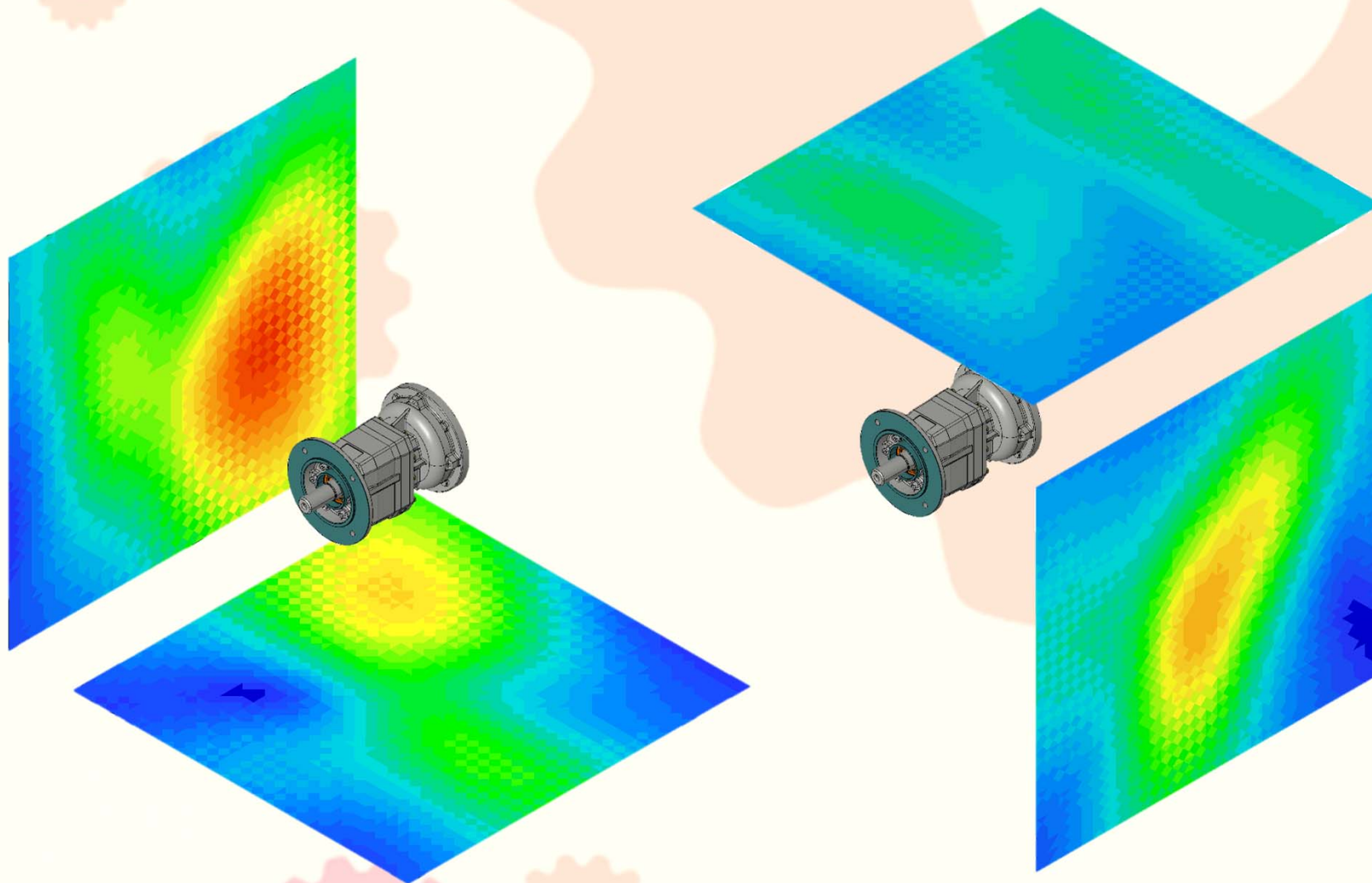


BE model of gearboxes

BEM indirect



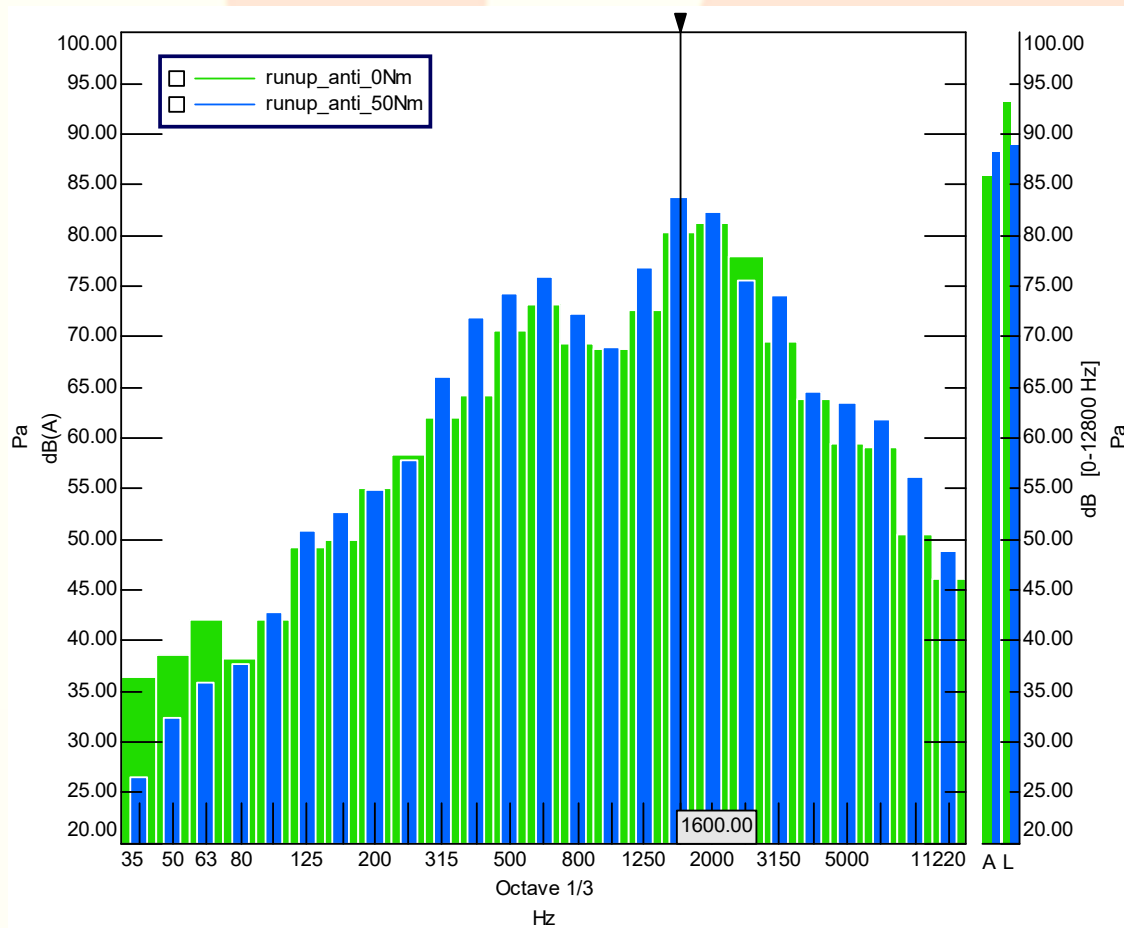
BE model of gearboxes – Results



BE model of gearboxes

Validation using Experimental data

Octave map - Microphone



High value at about
1600Hz—Z
> the BE analysis is
conducted at this
frequency

Sound Quality Analysis of gearboxes

Results of BE model
or experimental data



Matlab/Octave

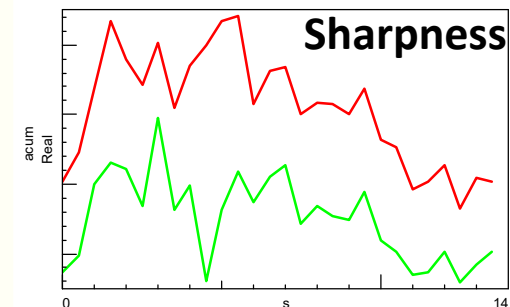
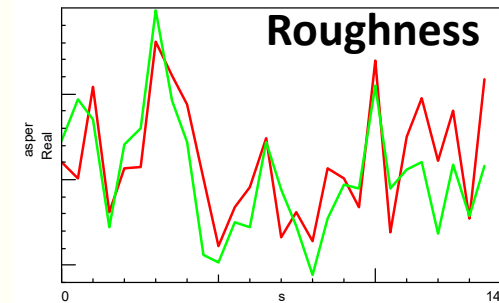
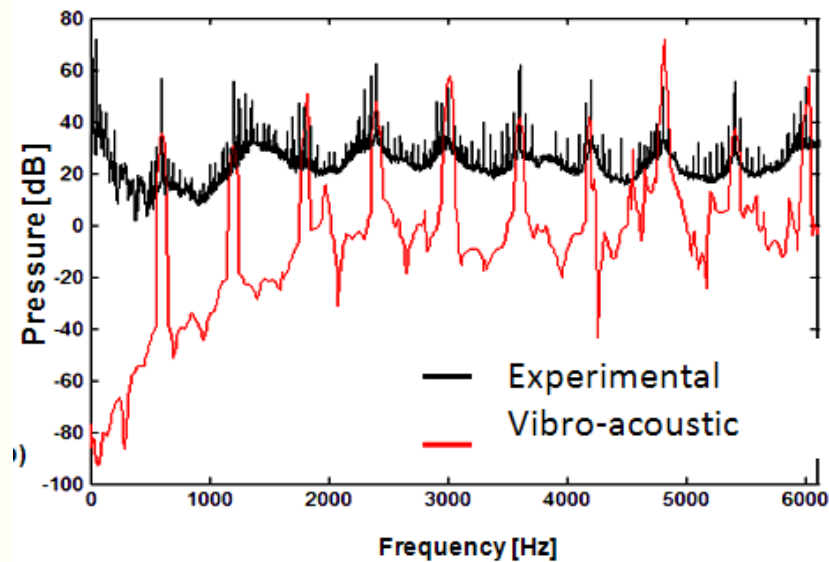


NVH Metrics:

- Loudness
- Sharpness
- Roughness
- Impulsiveness
- Modulation index



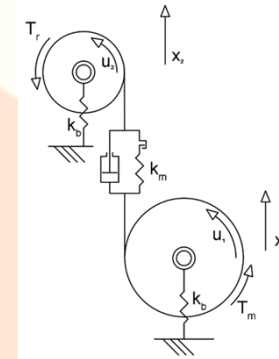
Sound quality of
gearboxes by using
numerical or
experimental data



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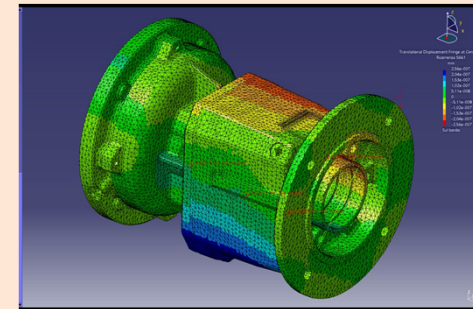
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Gear vibration/variable forces on bearings and casing



Parametric FE model of gearboxes

Natural frequency of casing/ casing vibration

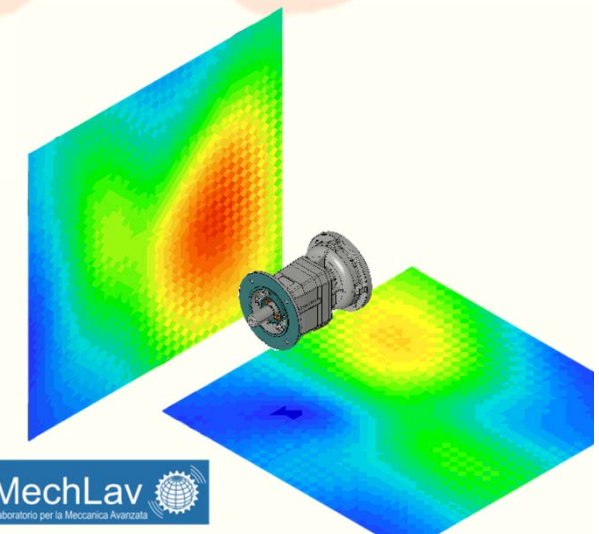


BE model of gearboxes

Acoustic radiation

Sound Quality Analysis of gearboxes

acoustic comfort/metrics





Conclusions

Software portfolio for NVH optimization of gearboxes:

- FE modelling
- LP modelling
- BE modelling
- Sound quality analysis

All models have been experimentally assessed

The methodology can be applied to every gearboxes



The background features a light yellow gradient with several gear icons. A large, semi-transparent orange gear shape is positioned on the right side. Smaller, solid orange gear icons are scattered on the left and bottom. The main text is centered in a green, italicized font.

Thanks for your kind attention

CONTACT:

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