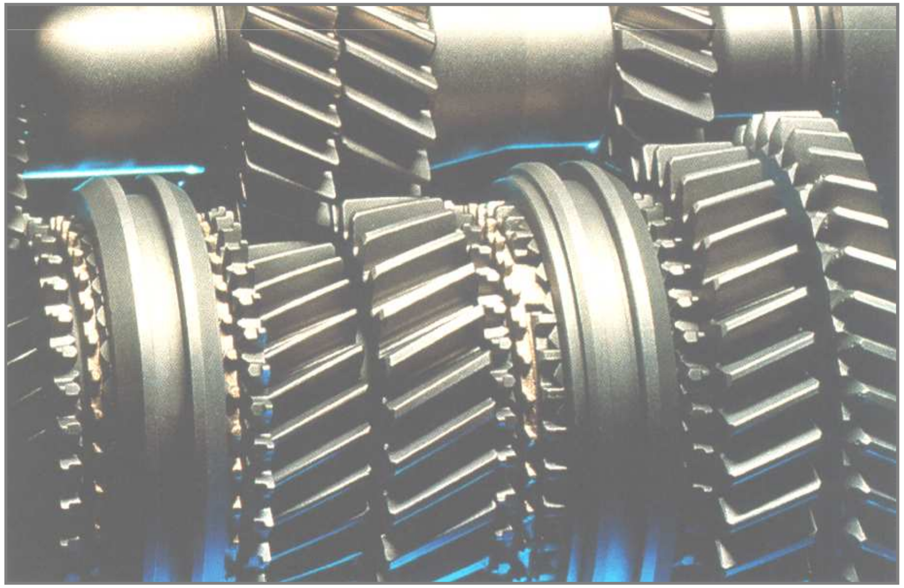
Experimental and numerical analysis of automotive gearbox rattle noise



Younes KADMIRI
Emmanuel RIGAUD, Joël PERRET-LIAUDET

ÉCOLE CENTRALE LYON

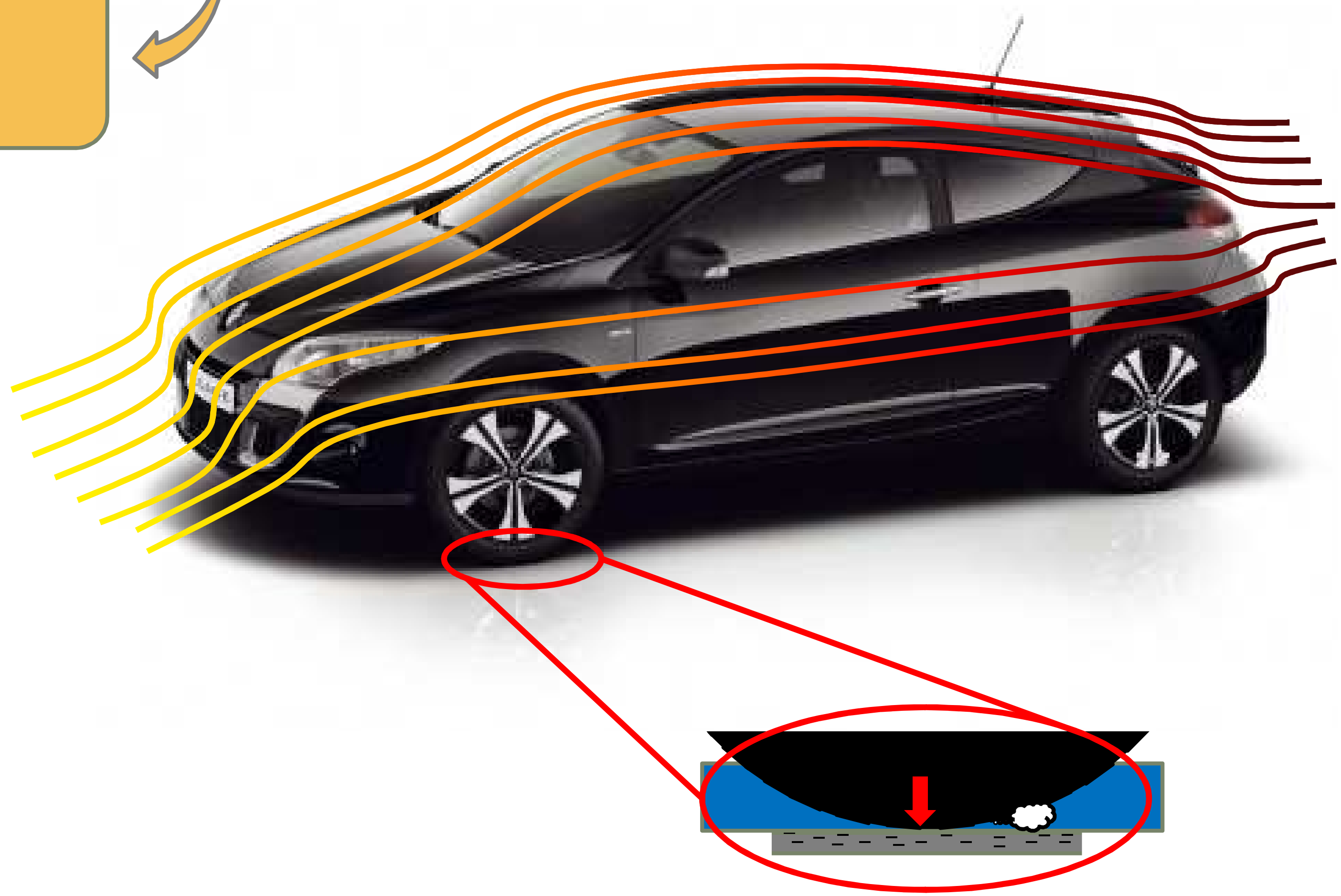
LTDS
Laboratoire de Tribologie et Dynamique des Systèmes

Journées GDR Visible, 18-19 mai 2011, IFSTTAR, Bron

Introduction

Improving acoustic confort

External noise sources:
- Aerodynamic
- Pneumatic



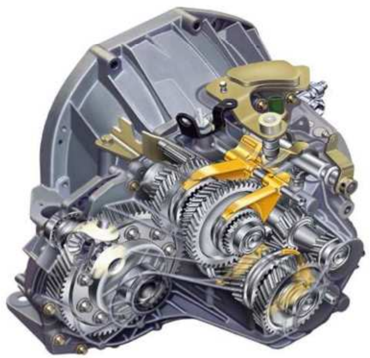
Introduction

Improving acoustic confort

External noise sources:
- Aerodynamic
- Pneumatic

Internal noise sources:
- Engine
- Gearbox
(gear whine, rattle noise)

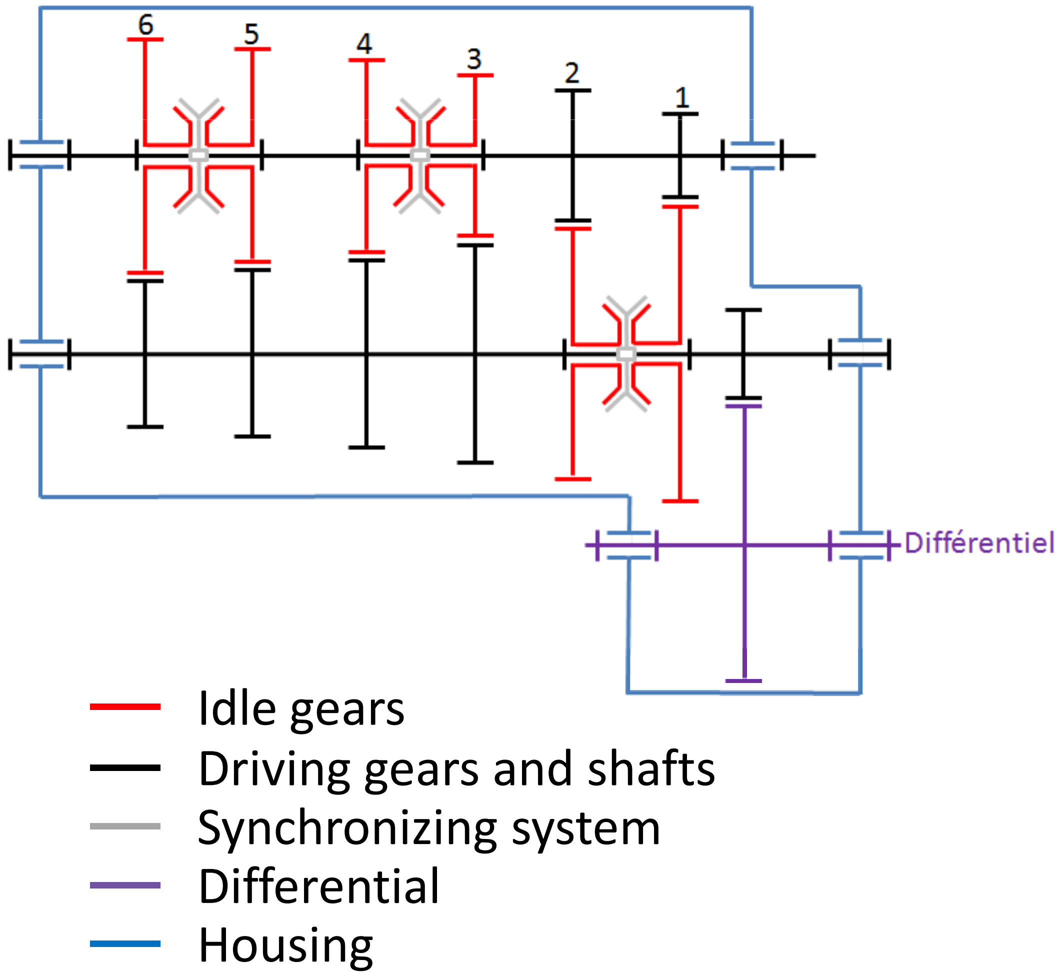
Engine



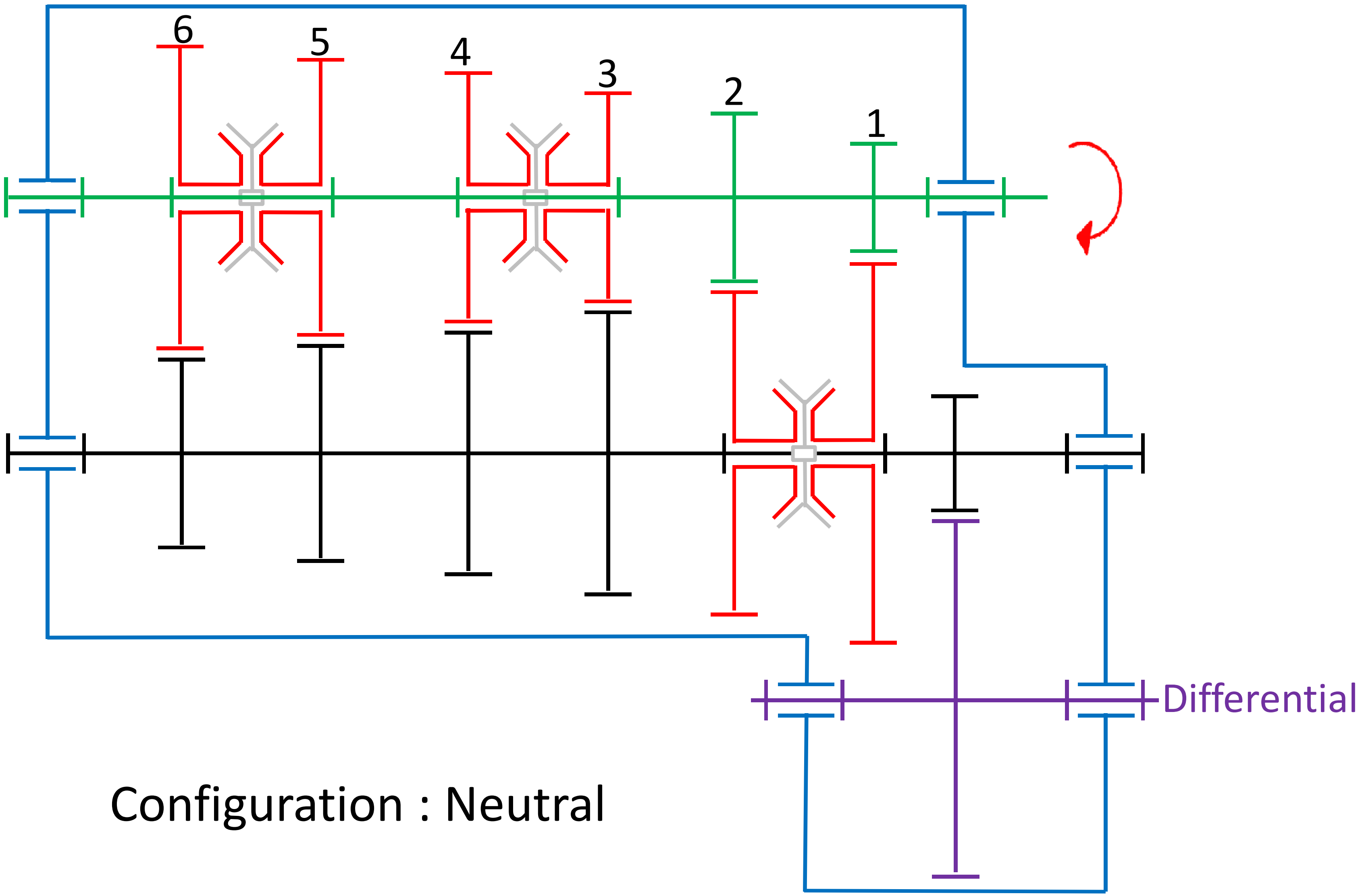
Gearbox

Introduction

Kinematic scheme of TL4 gearbox

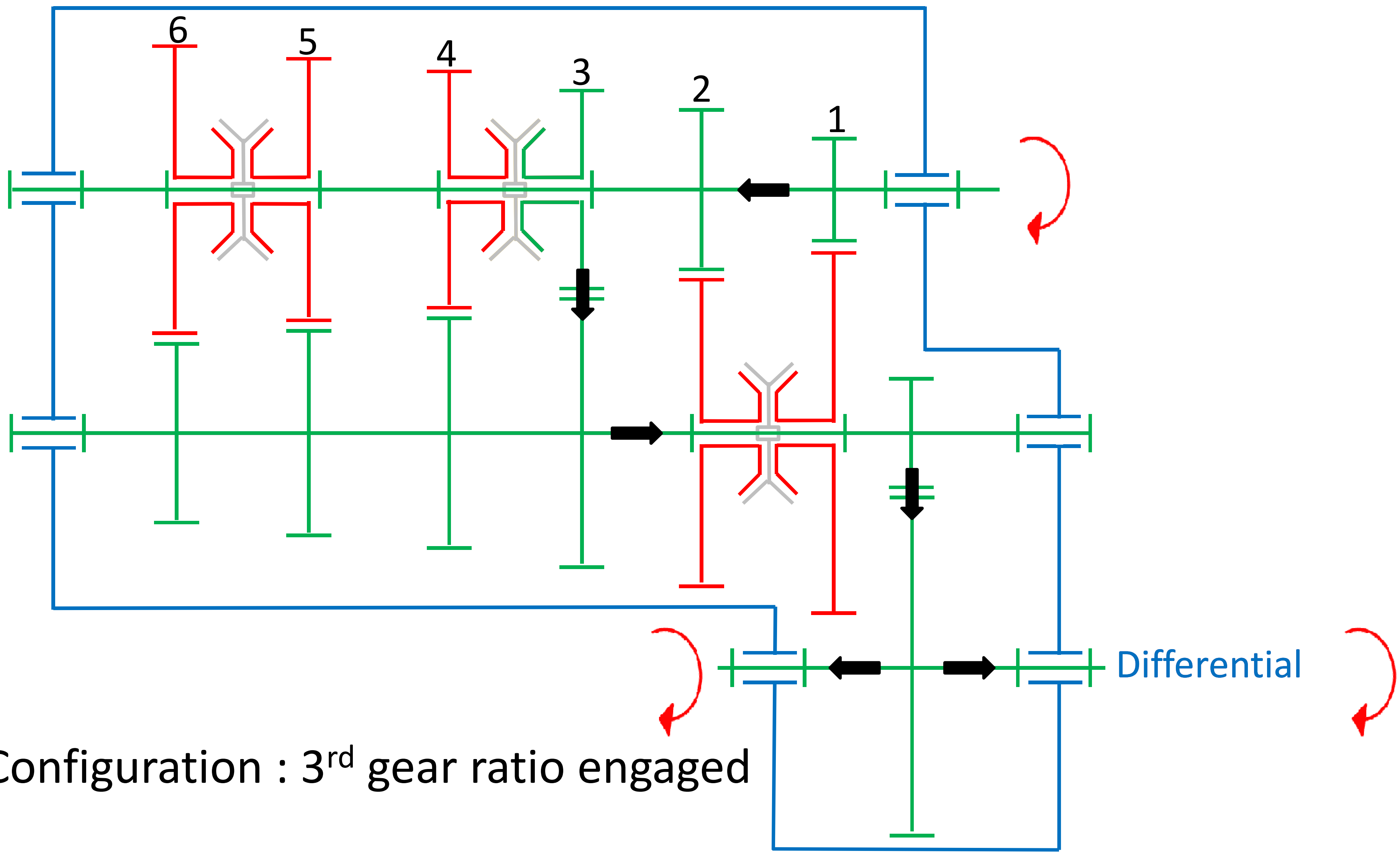


Introduction



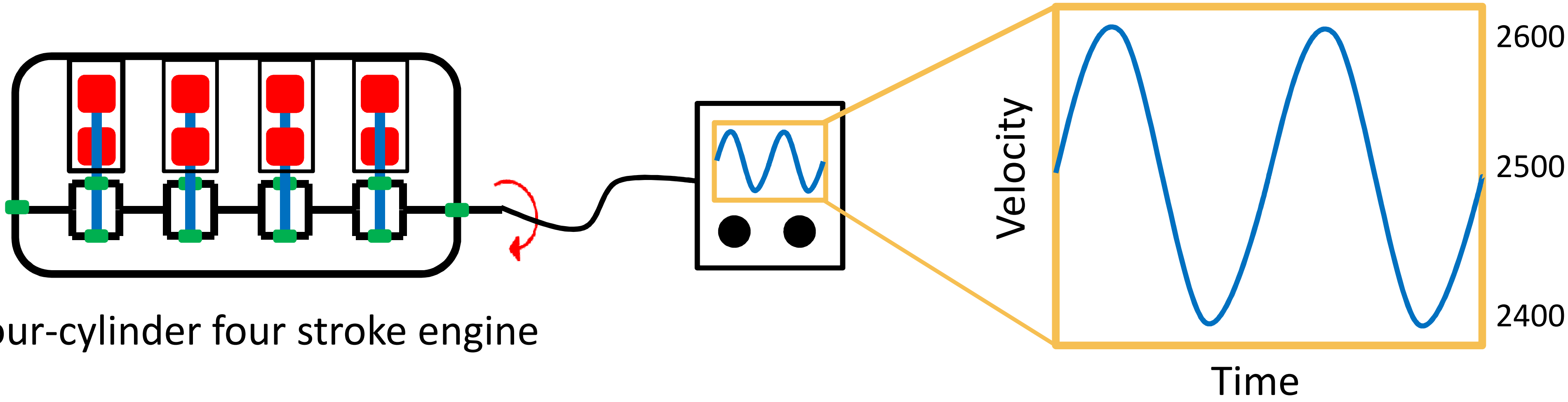
Configuration : Neutral

Introduction

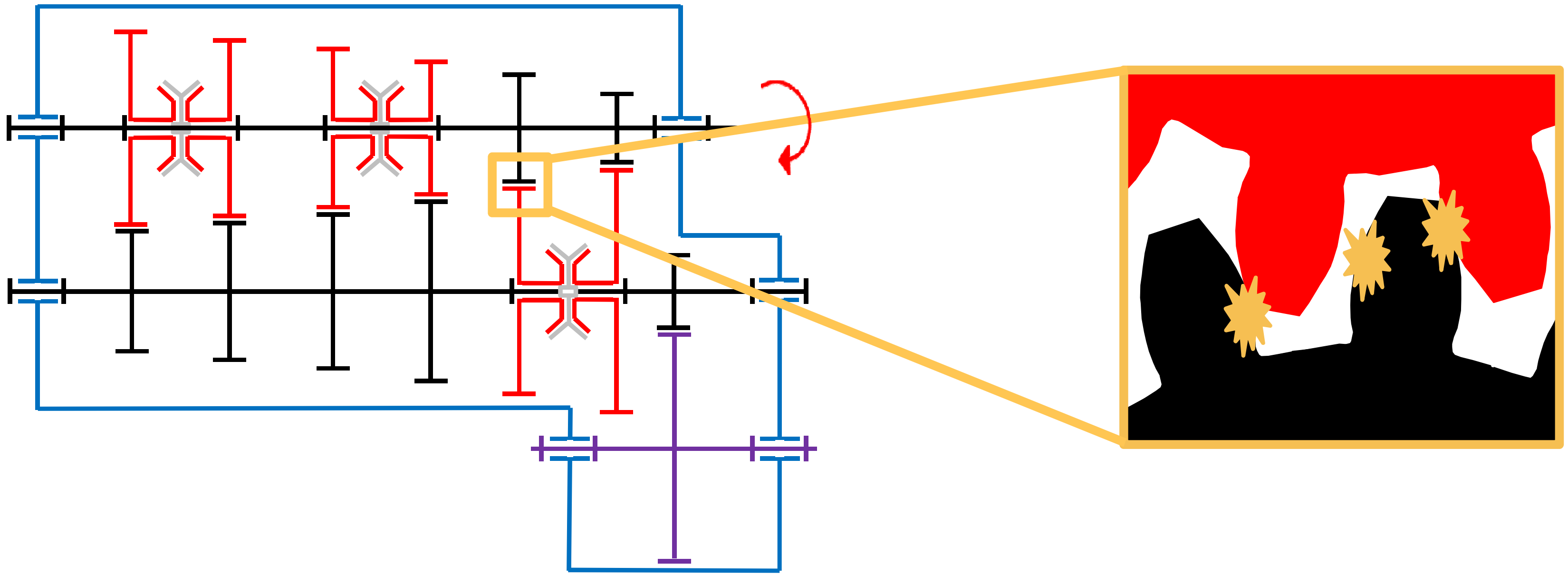


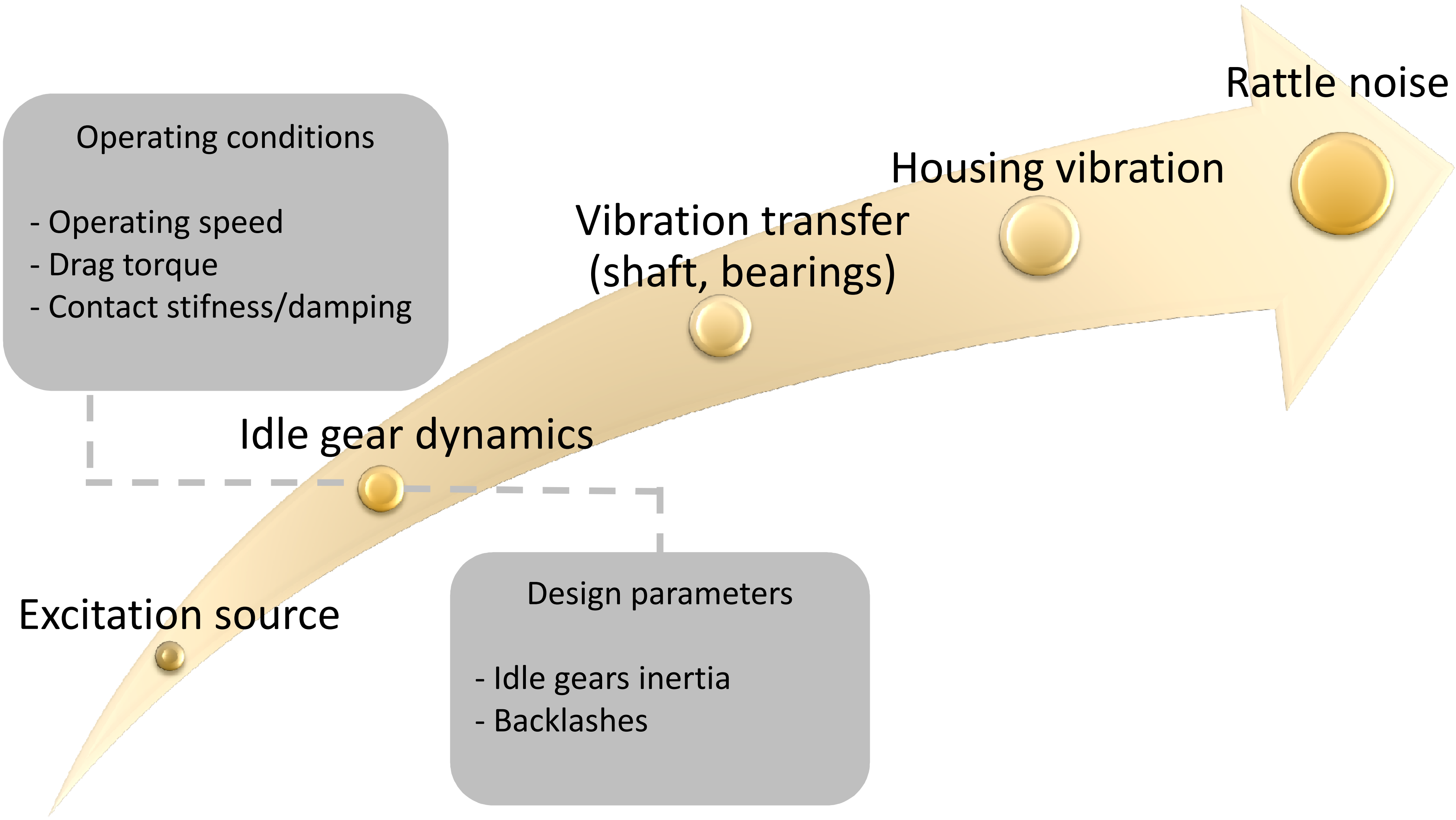
Configuration : 3rd gear ratio engaged

Introduction

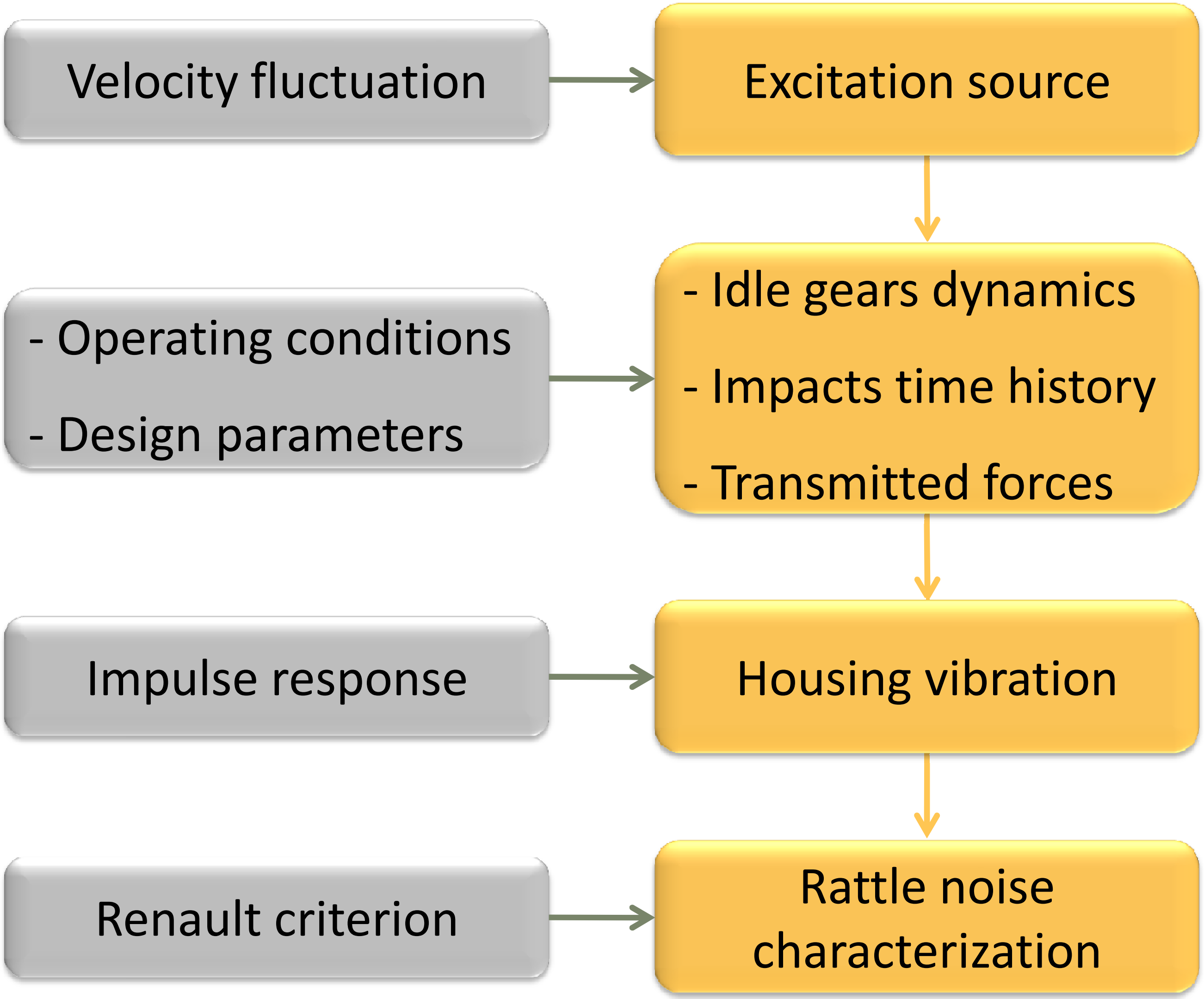


Four-cylinder four stroke engine

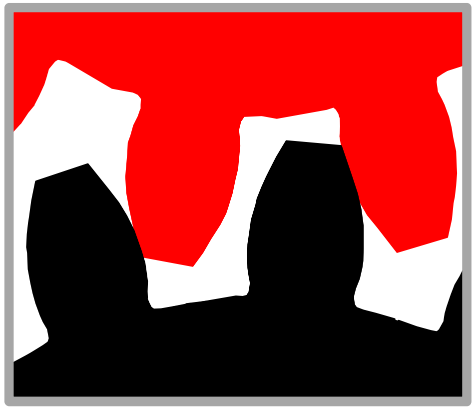



Rattle noise
Housing vibration
Vibration transfer (shaft, bearings)
Operating conditions
- Operating speed
- Drag torque
- Contact stifness/damping
Idle gear dynamics
Excitation source
Design parameters
- Idle gears inertia
- Backlashes

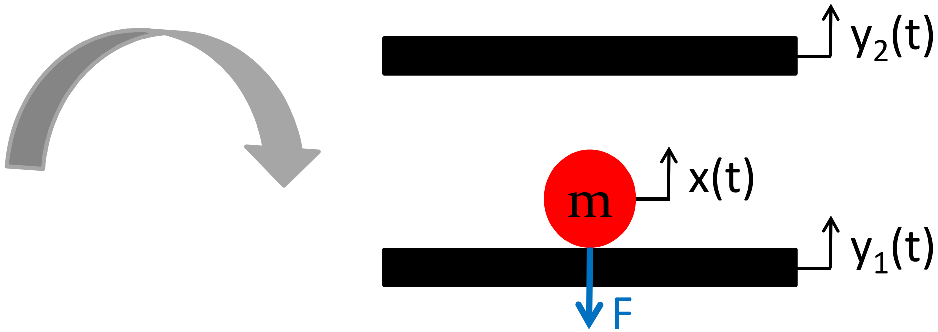
Numerical model



Non linear model

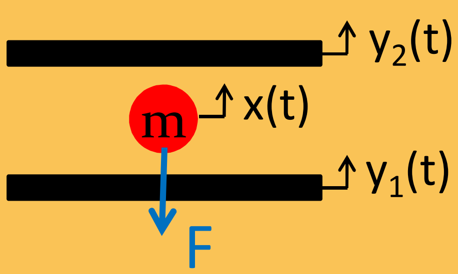


Angular displacement



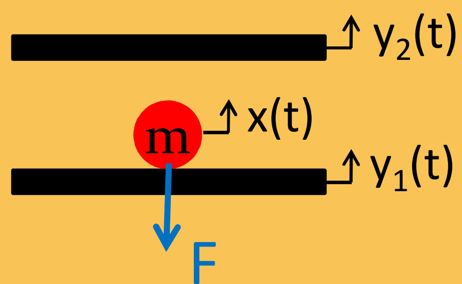
Displacement along the action line

Free fligth



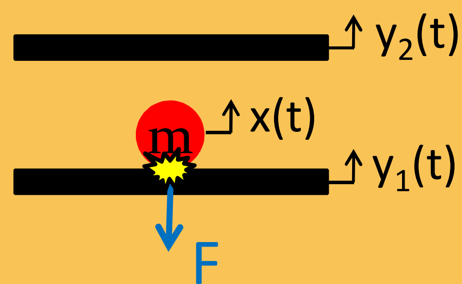
$$m\ddot{x} = -F$$

Permanent contact



$$0 < R_1(t) = F + m\ddot{y}_1(t)$$
$$0 > R_2(t) = F + m\ddot{y}_2(t)$$

Impacts



$$(\dot{x}^+ - \dot{y}_i^{\,+}) = -r(\dot{x}^- - \dot{y}_i^{\,-})$$
$$0 \le r \le 1$$

Dimensionless non linear model

6 variables necessary to describe rattle noise (m, F, r, H, j, ω)

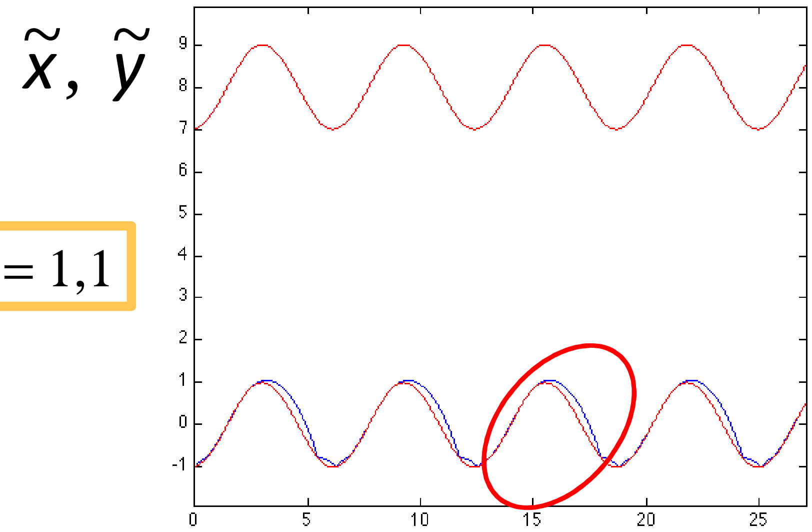
Vaschy-Buckingham theorem

3 dimensionless numbers

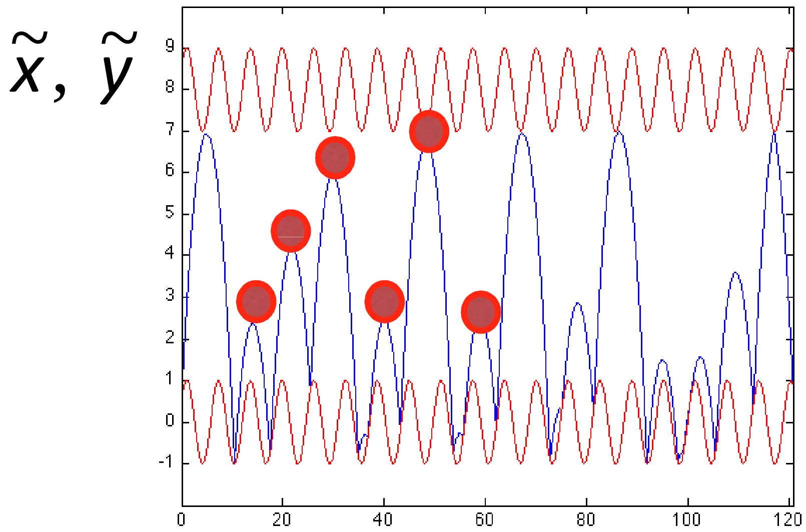
- r
- $\tilde{j} = \frac{j}{H}$
- $\Lambda = \frac{mH\omega^2}{F}$

Time responses for $\tilde{j} = 8, r = 0.85$

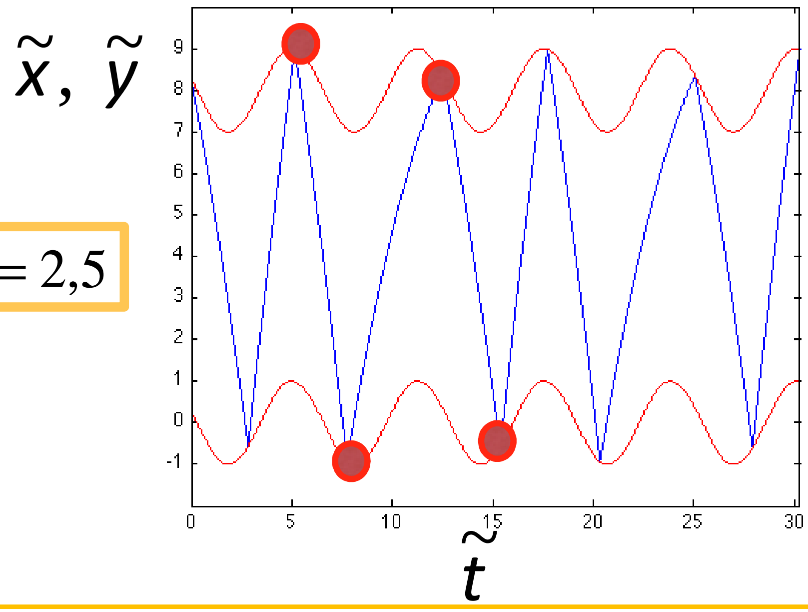
$\Lambda = 1,1$



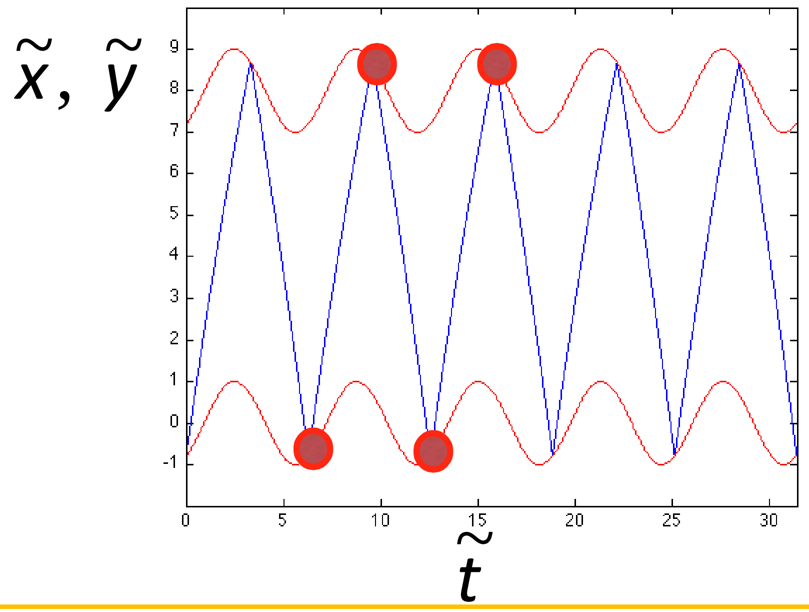
$\Lambda = 1,5$



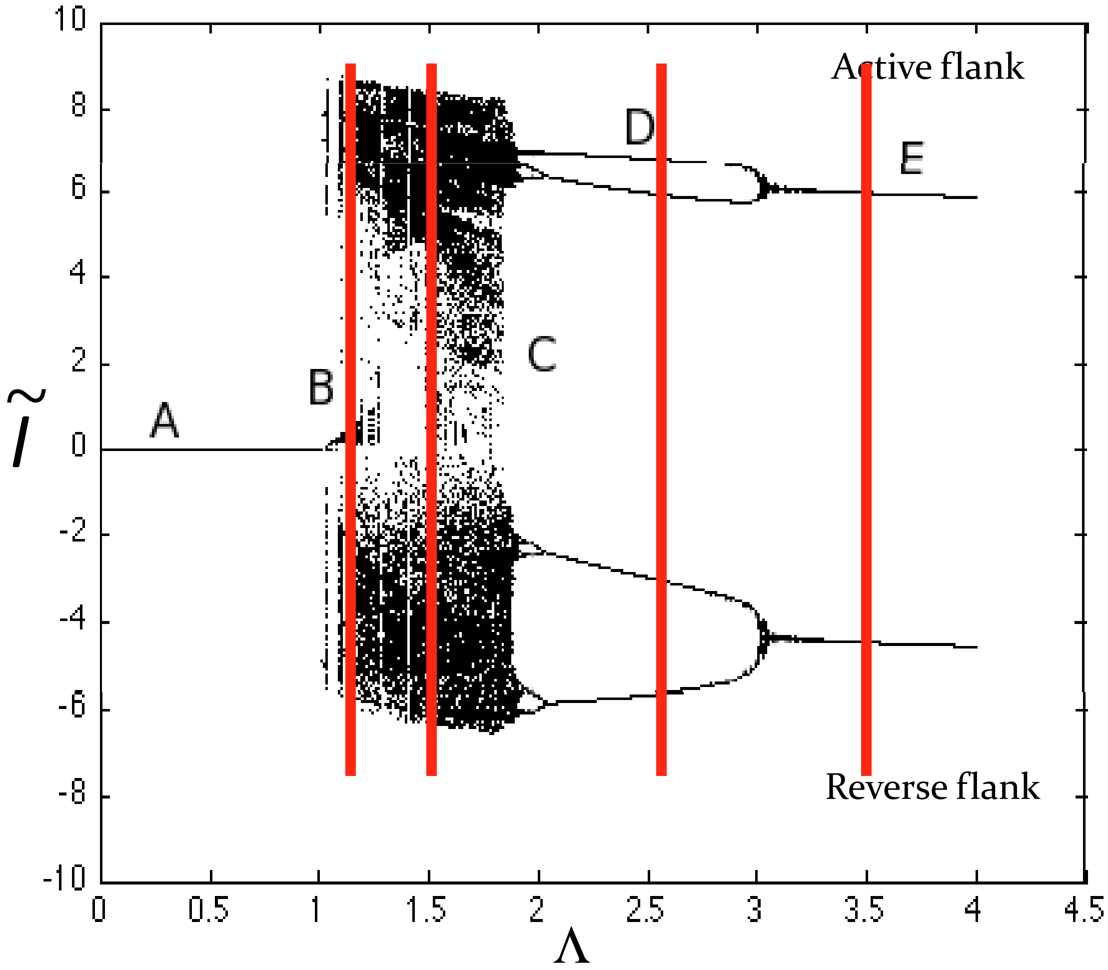
$\Lambda = 2,5$

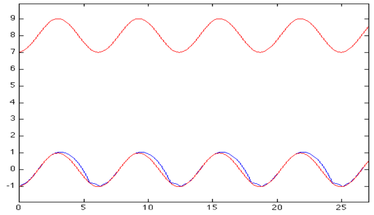


$\Lambda = 3,5$

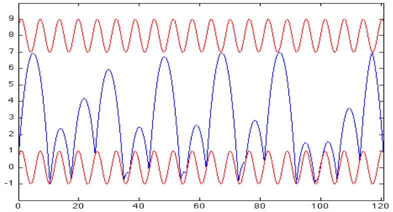


Impulses diagram

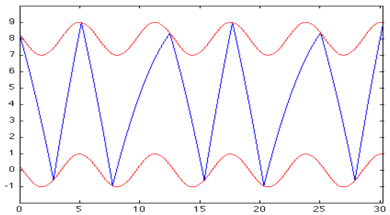




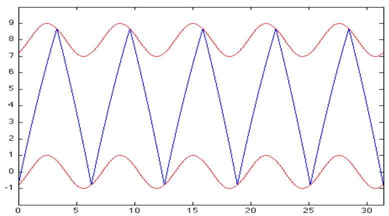
B: rebounds and contact intermittency



C: chaotic response

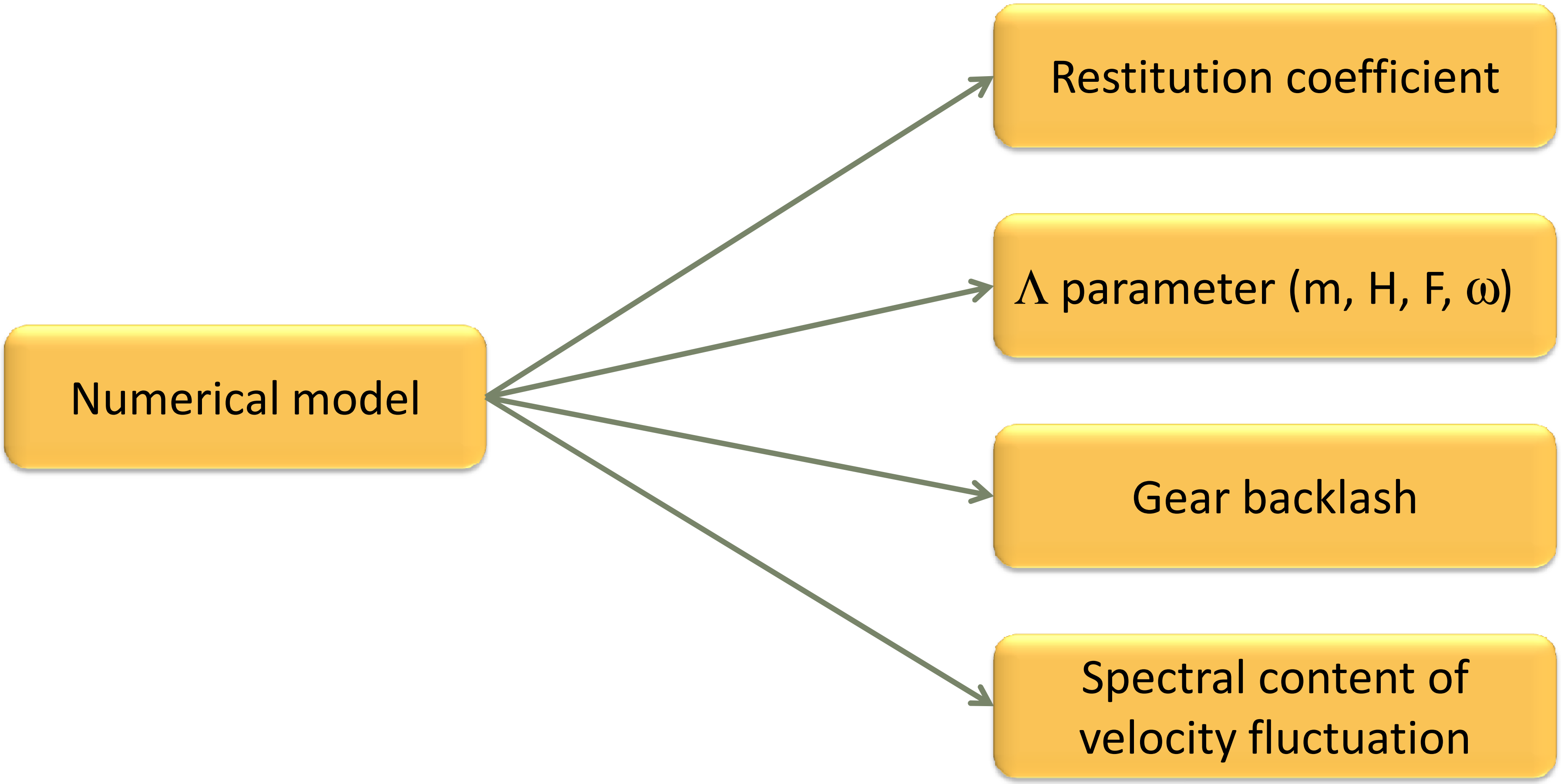


D: 2T 2 impacts response



E: 1T 2 impacts response

Conclusion

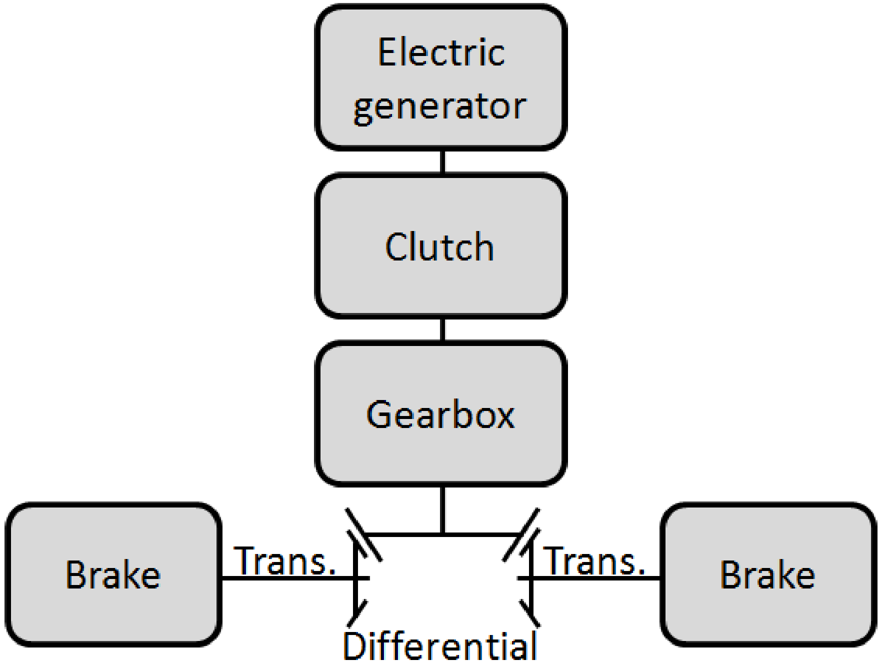


Measuring these parameters is necessary

Test bench (BACY)

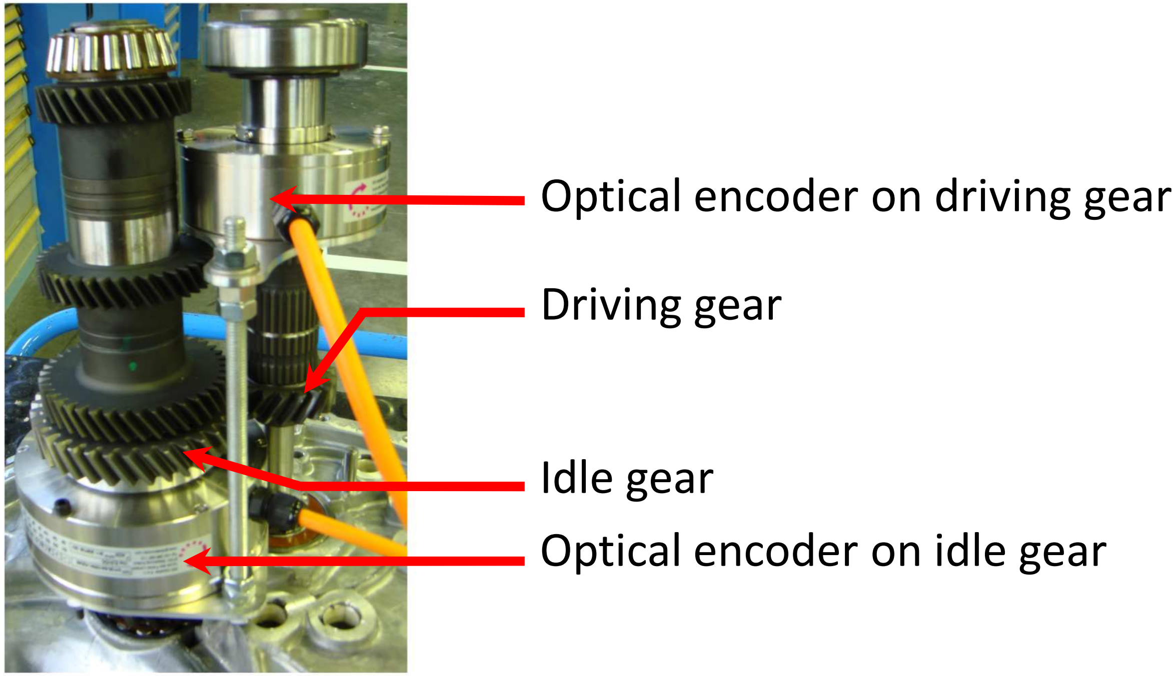
Experiments performed :

- Key parameters measurement (restitution coeff., drag torque, …)
- Idle gear dynamics measurement
- Housing vibration measurement
- Radiated noise measurement.



Gearbox instrumentation

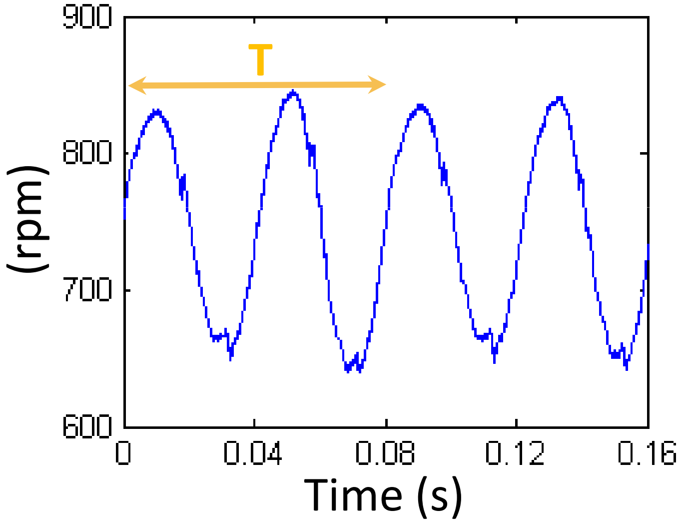
- Weak dimensions
- Small gear backlash = 0.1 mm
- Idle gear and supporting shaft are indepedant
- Severe operating conditions (high Ω, oil churning, high T, ...)



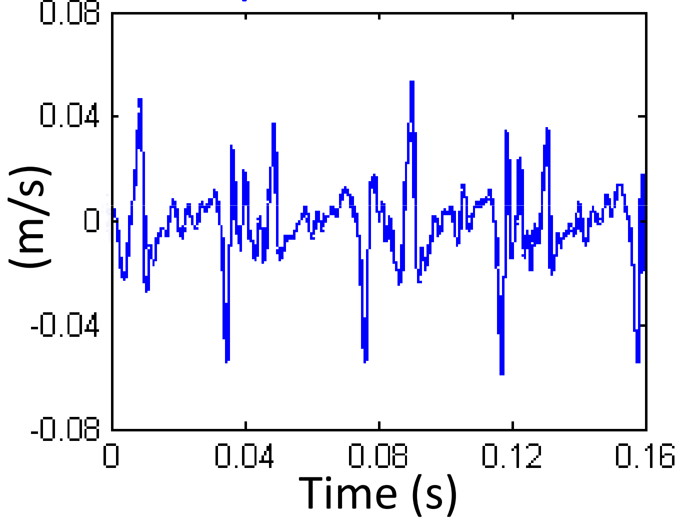
Configuration : 2nd gear ratio

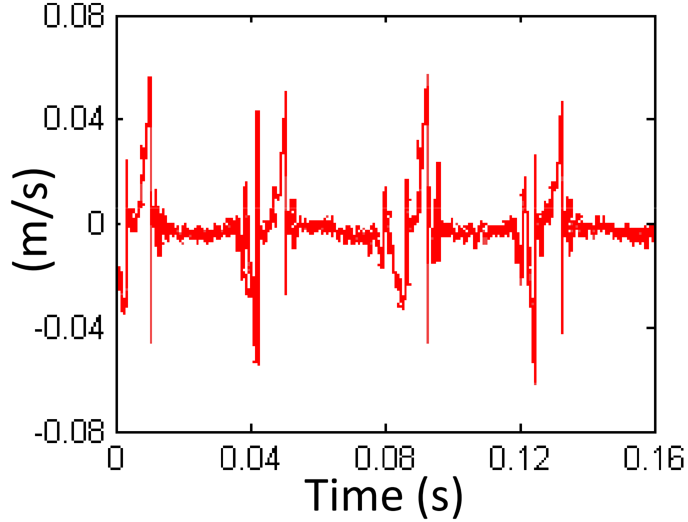
Configuration : 2nd, 3rd and 4th gear ratio

Idle gear dynamics



Experimental and simulated relative velocities

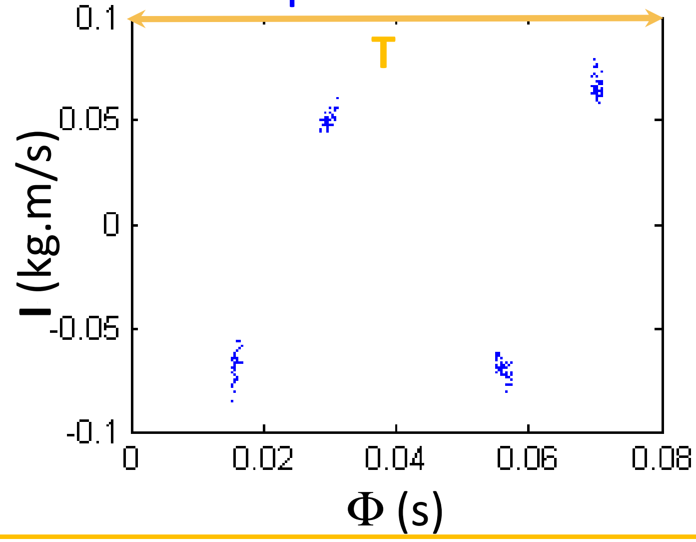


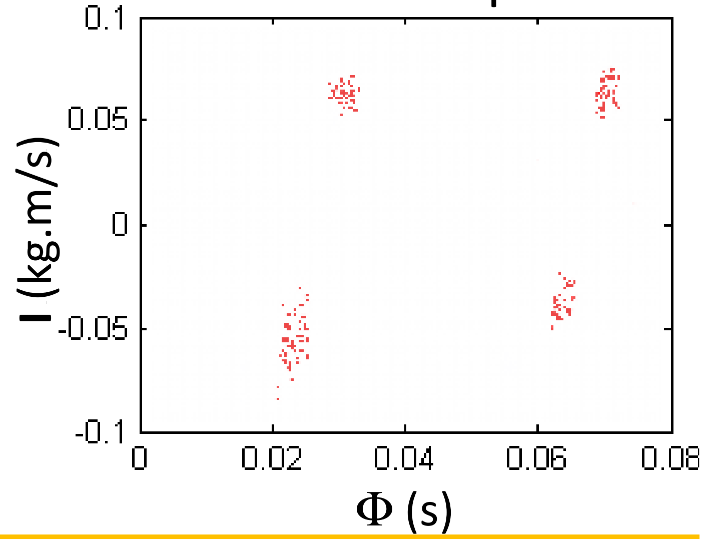


Ω = 750 rpm et A = 50 rpm

Neutral

Experimental and simulated Poincaré maps





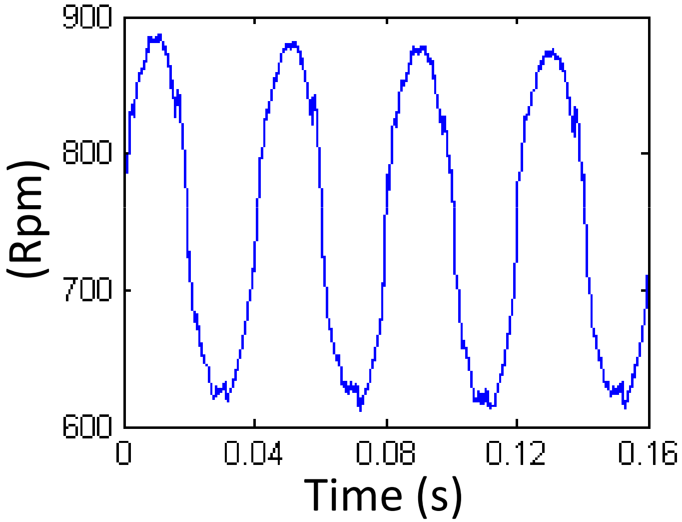
$$\Phi_i = t_i \, [T]$$

Φ : phase (s)

t_i : Impact time

T : period

Idle gear dynamics



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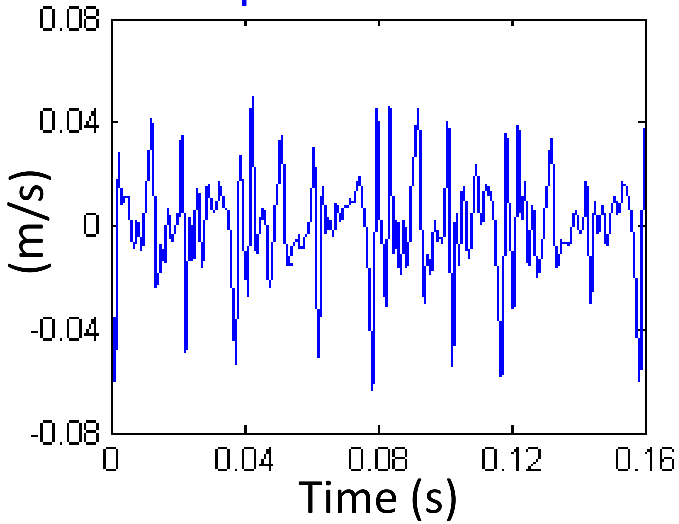
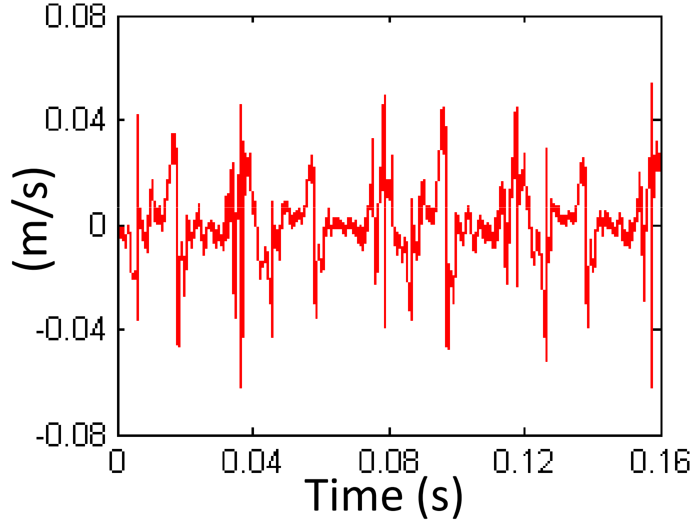
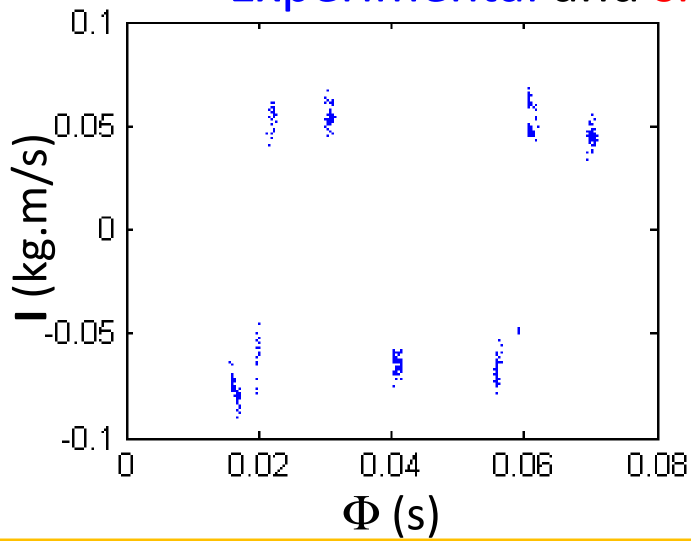


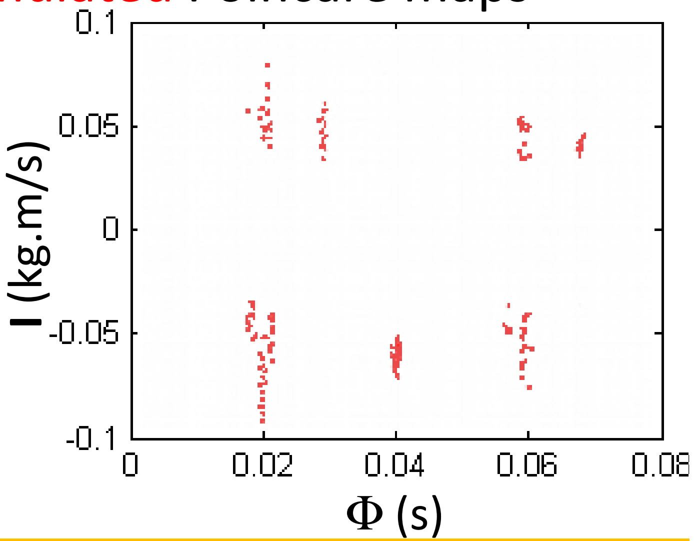


Ω = 750 rpm et A = 100 rpm

Neutral

Experimental and simulated Poincaré maps





$$\Phi_i = t_i \left[T\right]$$

Φ : phase (s)

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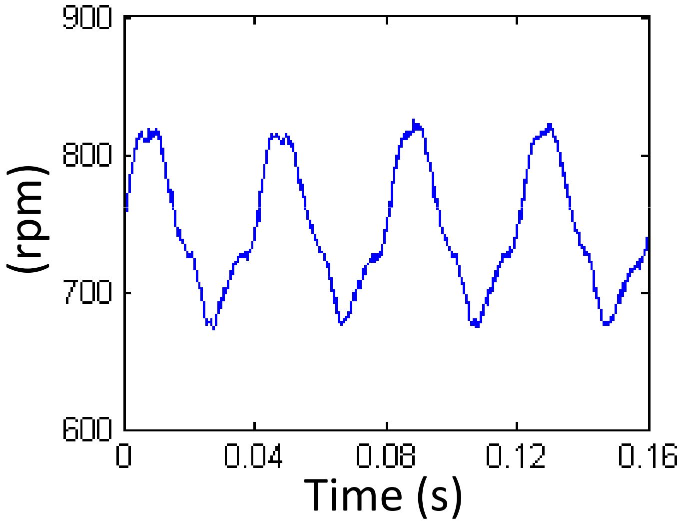
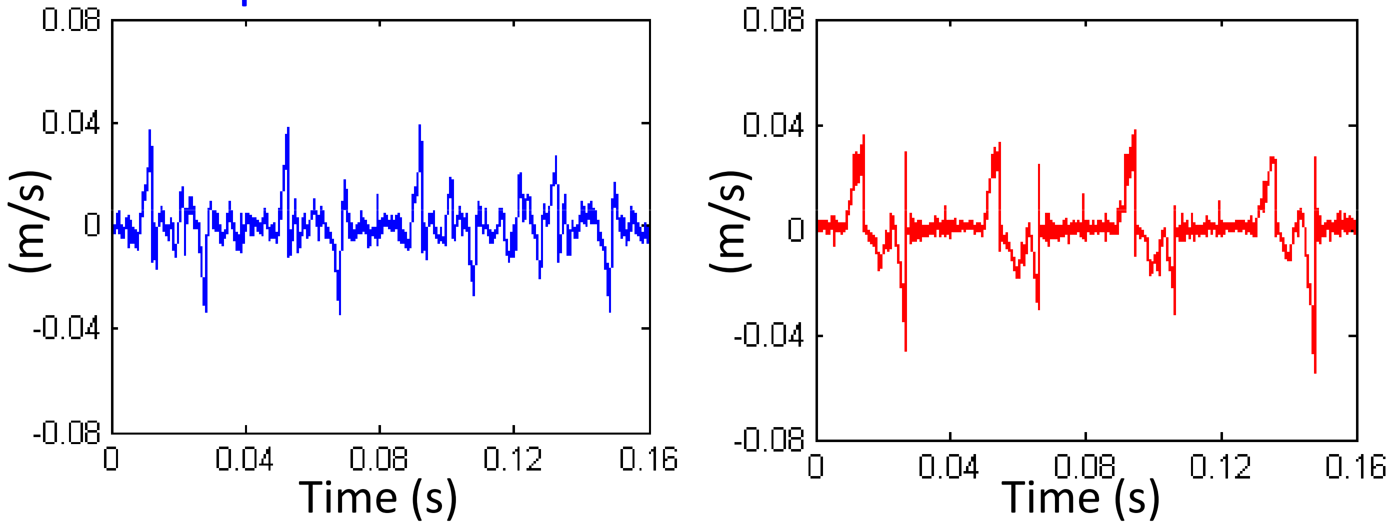
T : period

Idle gear dynamics



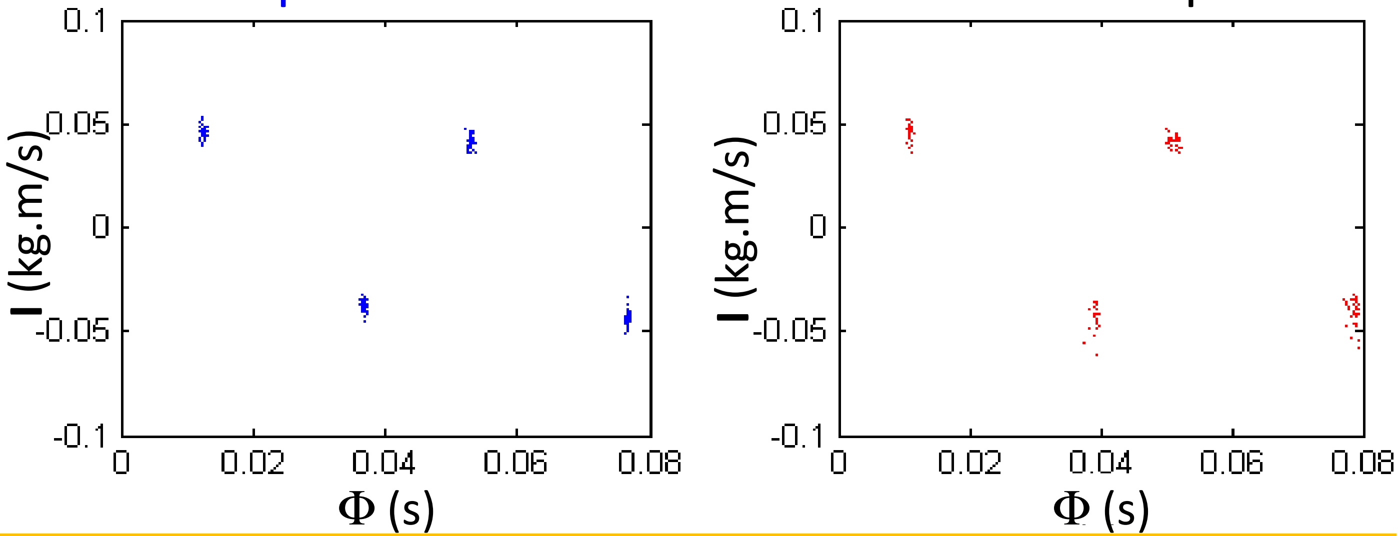
Experimental and simulated relative velocities



Ω = 750 rpm et A = 125 rpm

3rd ratio engaged

Experimental and simulated Poincaré maps



$$\Phi_i = t_i \, [T]$$

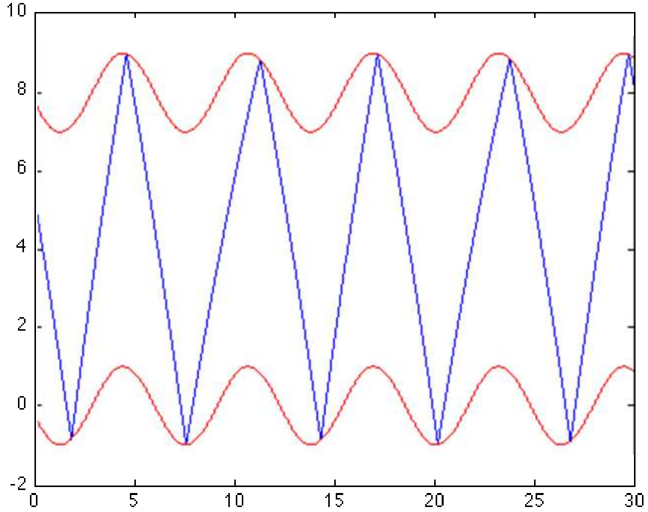
Φ : phase (s)

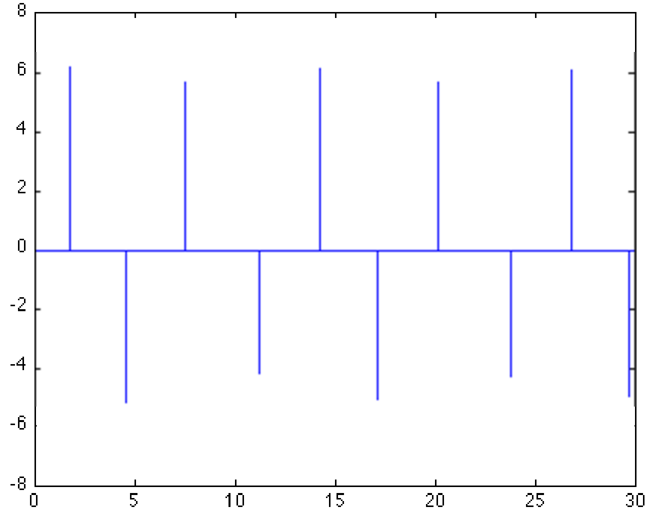
t_i : Impact time

T : period

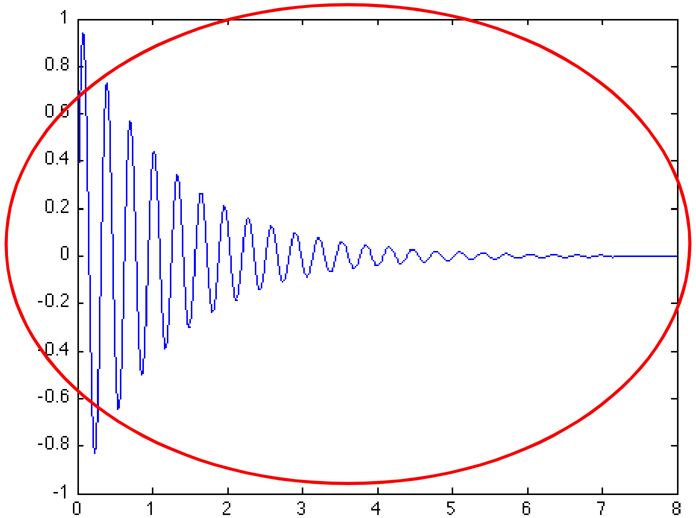
Housing vibration

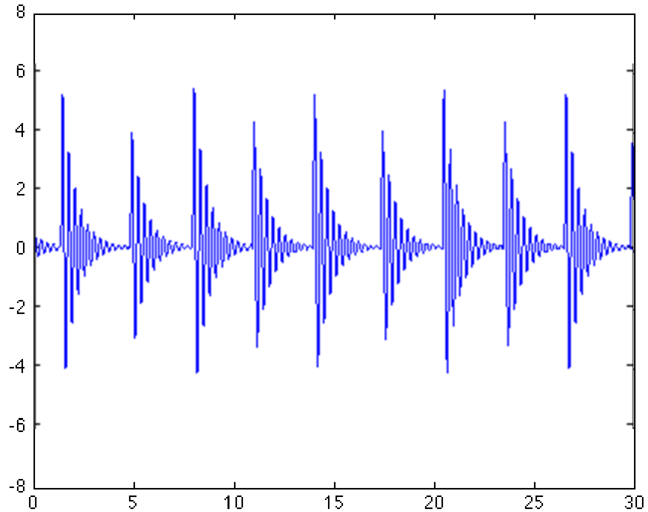
Model outputs


Time response

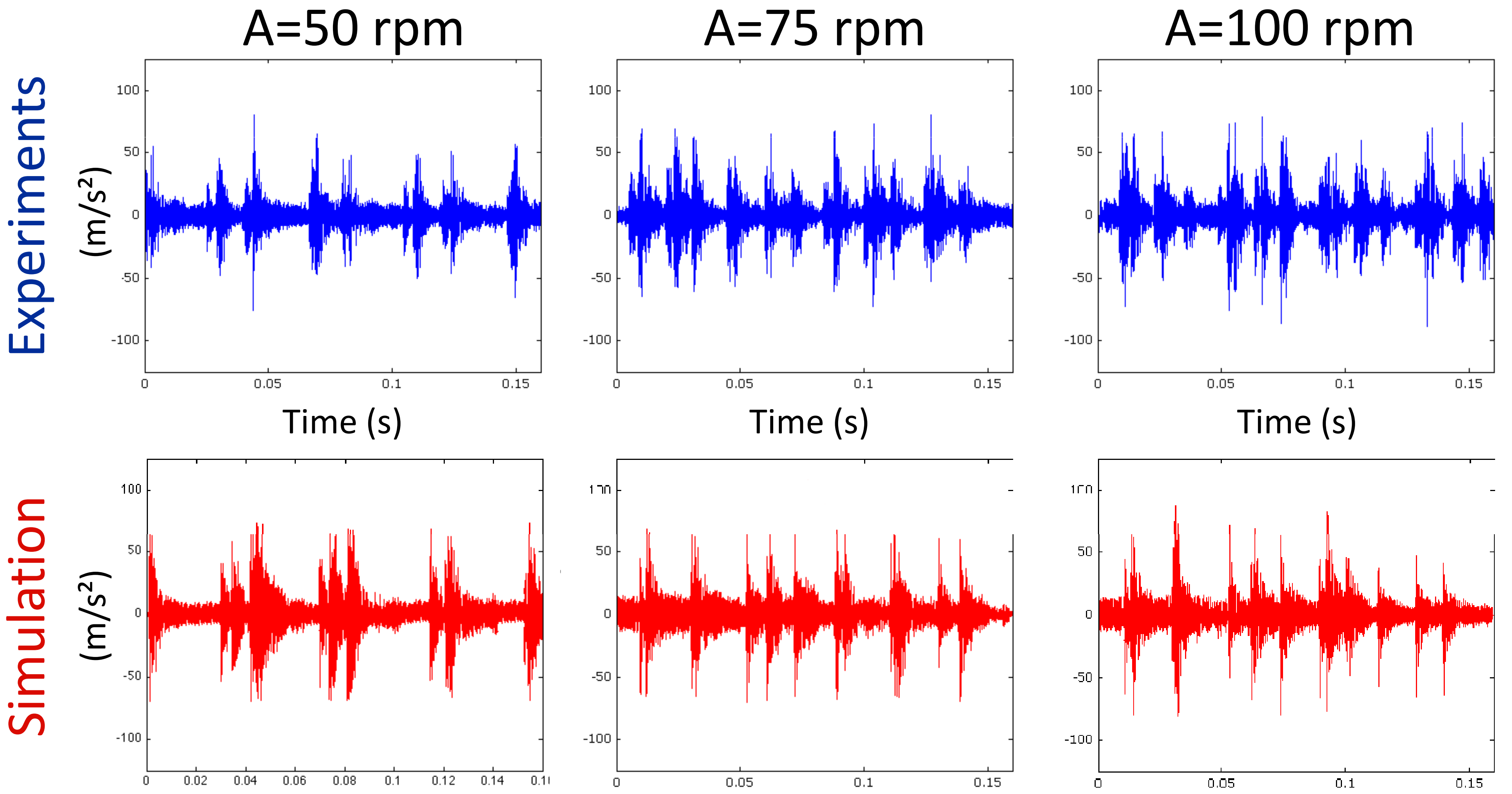

Successive impulses

Housing response

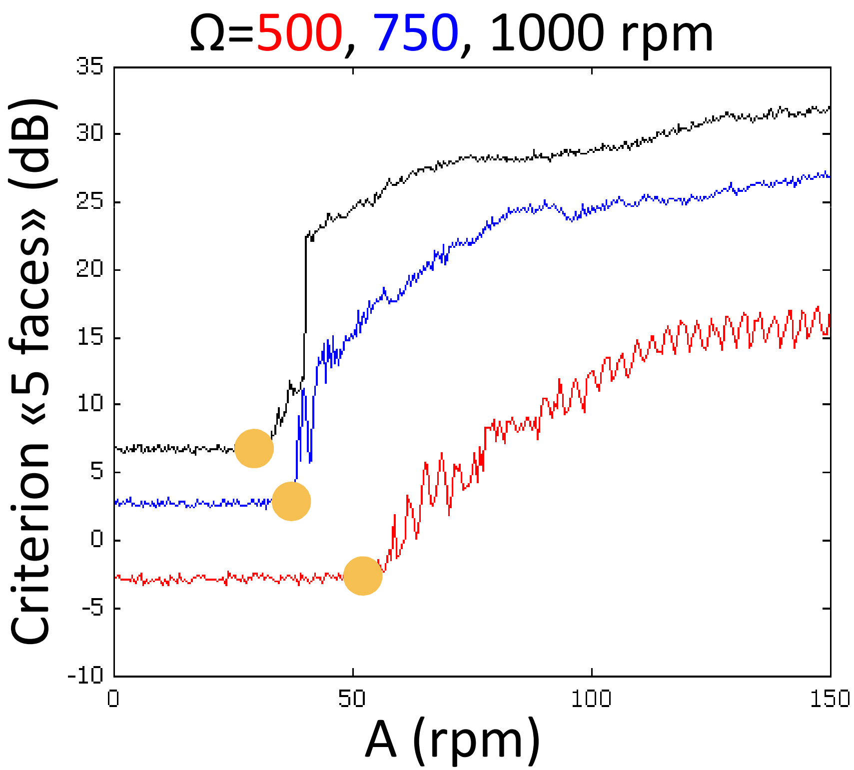

Measured transfer fonction

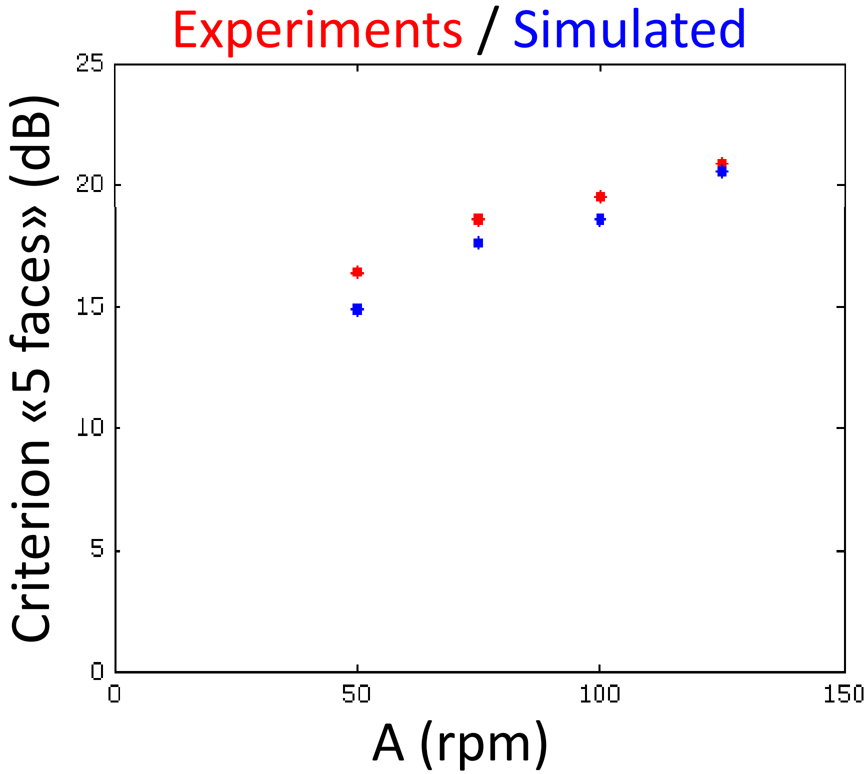

Housing response

Housing vibration Ω=750 rpm



Renault Criterion «5 faces»





A	**50 rpm**	**75 rpm**	**100 rpm**	**125 rpm**
Experiments	16,4 dB	18,6 dB	19,5 dB	20,9 dB
Simulation	14,9 dB	17,6 dB	18,6 dB	20,6 dB
Error	1,5 dB	1,0 dB	0,9 dB	0,3 dB

Conclusion

- Experiments performed with BACY allowed non linear numerical model.

- Operational software.

- Rattle noise can be predicted for:
  - any gearbox,
  - any gear ratio,
  - any operating conditions.

- Parametric studies allow gearbox design optimization.