

The role of the tyre in traction-induced driveline vibrations

By

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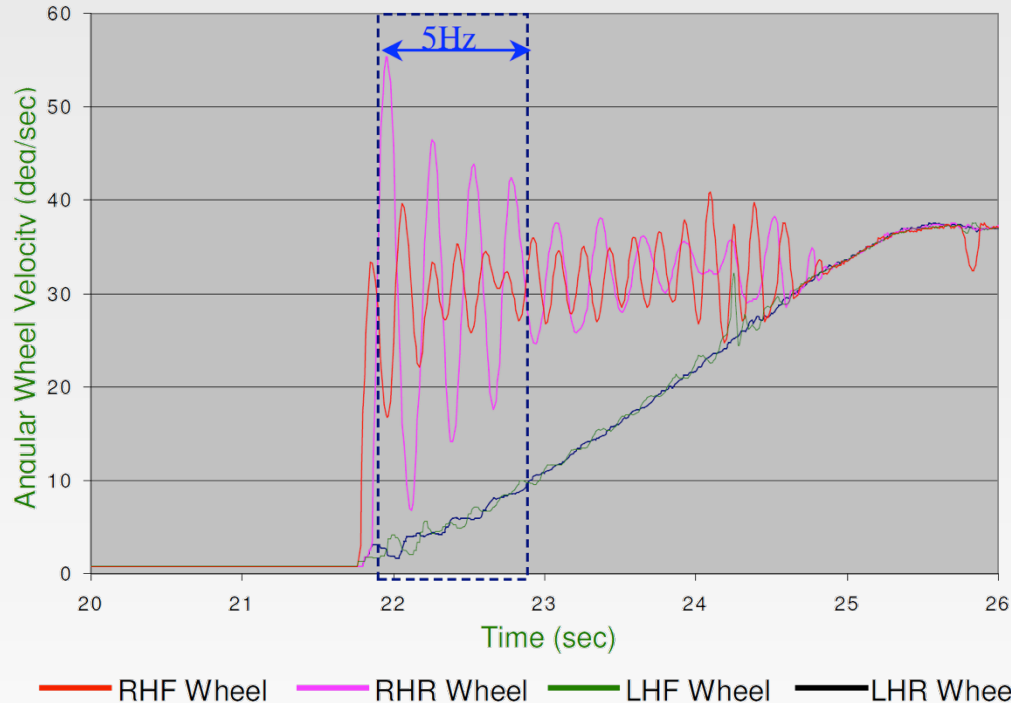
Cambridge, UK

Overview of presentation

- ❑ Low speed traction and associated problems
- ❑ Scope of research – method of attack
- ❑ Modelling and simulation
- ❑ Experimental investigation
- ❑ Concluding remarks

Low speed traction and associated problems

Wheel speed variation of a 4WD vehicle during traction manoeuvre on split- μ surface



Observations:

- a) Nominal shuffle freq. on high friction road: 2.1-2.2 Hz
- b) Low/split- μ surfaces lead to “**frequency migration**” (5.5 Hz)
- c) Phenomenon initially attributed to changing levels of damping in the driveline

Pawar, J., Biggs, S. and Jones, R.P., 2007. Sensitivity of System Boundary Conditions on the Migration of Low Frequency Modes Controlling Longitudinal Vehicle Response. 21st Biennial ASME Conference on Mechanical Vibration and Noise.

Scope of research

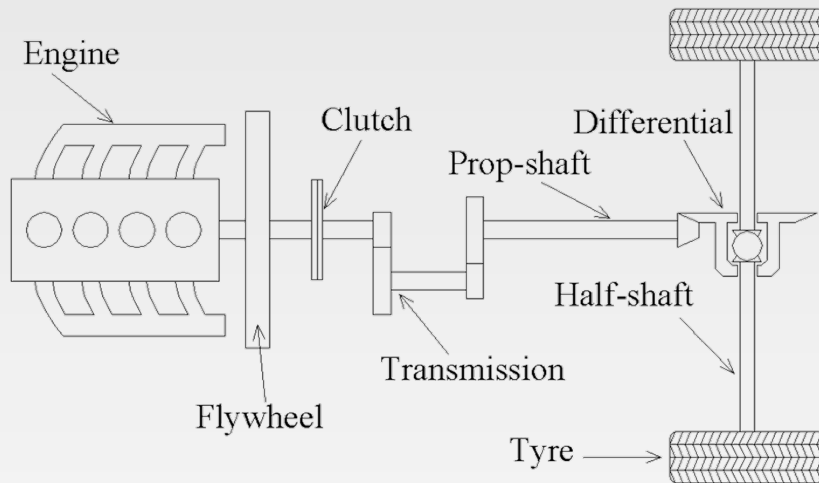
- a) To understand the effect of the tyre-road contact on the **severity** and **frequency content** of low frequency driveline oscillations during traction manoeuvres
- b) To understand the contribution of low frequency tyre structural dynamics in driveline oscillations
- c) To investigate the influence of “secondary” components such as the suspension
- d) To create predictive tools that will allow driveline refinement at an early stage of design

Method of attack

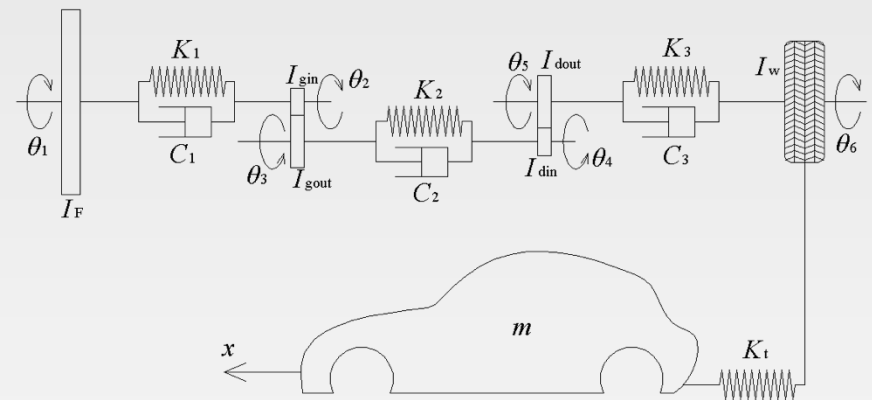
- a) Create driveline/vehicle models of 2WD and 4WD vehicles
- b) Combine driveline/vehicle models with tyre models of increasing complexity
- c) Obtain results in the time and frequency domains
- d) Linearise models and study the relevant vibration modes of the driveline
- e) Supplement with experimental measurements

Modelling and simulation

Driveline/vehicle modelling



Driveline schematic



Lumped parameter model

Models implemented:

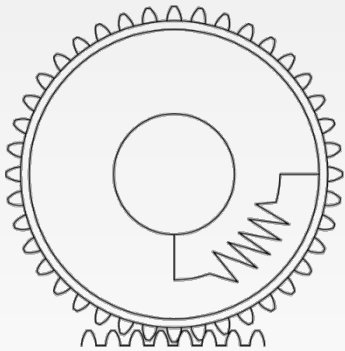
- Manual RWD driveline with open differential
- RWD driveline with auto transmission/torque converter
- 4WD driveline with manual transmission coupled with 6 DOF vehicle model + suspension kinematic model

Modelling and simulation

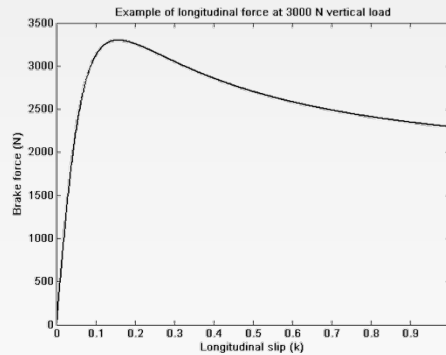
Tyre modelling

Models implemented:

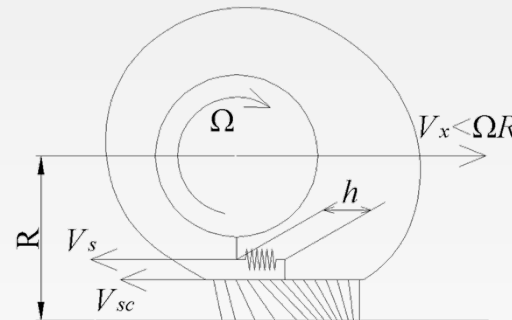
- Tyre as a torsional spring with its belt “geared to the ground” (kinematic relationship)
- Steady-state (Magic Formula)
- Non-linear relaxation length + Magic Formula model
- Rigid ring model with torsional and translational belt modes (in-plane) + Magic Formula



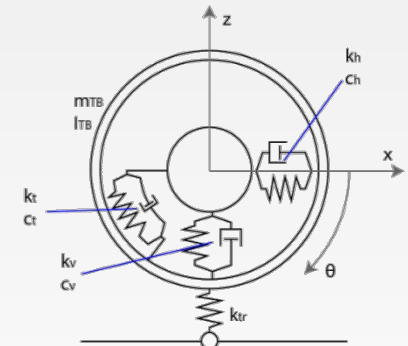
a.



b.



c.



d.

Modelling and simulation

Baseline results for RWD driveline with open differential on high- μ road

Forward speed: 0.5 m/s

Model	Torsional spring		Magic Formula		Relaxation length	
Mode	Damping ratio	Damped freq (Hz)	Damping ratio	Damped freq (Hz)	Damping ratio	Damped freq (Hz)
6	0.0172	443.5	0.0173	443.5	0.0172	443.5
5	0.0071	226.8	0.0076	225.1	0.0071	226.8
4	0.0764	73.7	0.0805	72.6	0.0764	73.7
3	0.0071	30.8	> 1	0	0.0081	30.8
2	0.0000	20.6	> 1	0	0.0032	20.6
1	0.0003	2.4	0.0240	3.6	0.0159	2.4
0	0.0000	0 (RB)	0.0000	0 (RB)	0.0000	0 (RB)

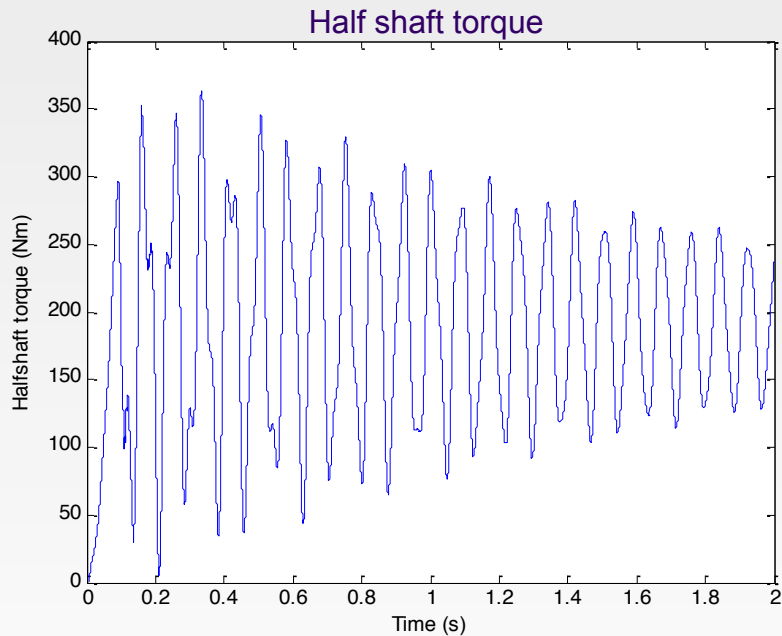
Forward speed: 5 m/s

Model	Torsional spring		Magic Formula		Relaxation length	
Mode	Damping ratio	Damped freq (Hz)	Damping ratio	Damped freq (Hz)	Damping ratio	Damped freq (Hz)
6	0.0172	443.5	0.0173	443.5	0.0172	443.5
5	0.0071	226.8	0.0106	225.6	0.0071	226.8
4	0.0764	73.7	0.0829	72.6	0.0764	73.7
3	0.0071	30.8	> 1	0	0.0165	30.8
2	0.0000	20.6	> 1	0	0.0321	20.6
1	0.0003	2.4	0.2307	3.5	0.1559	2.4
0	0.0000	0 (RB)	0.0000	0 (RB)	0.0000	0 (RB)

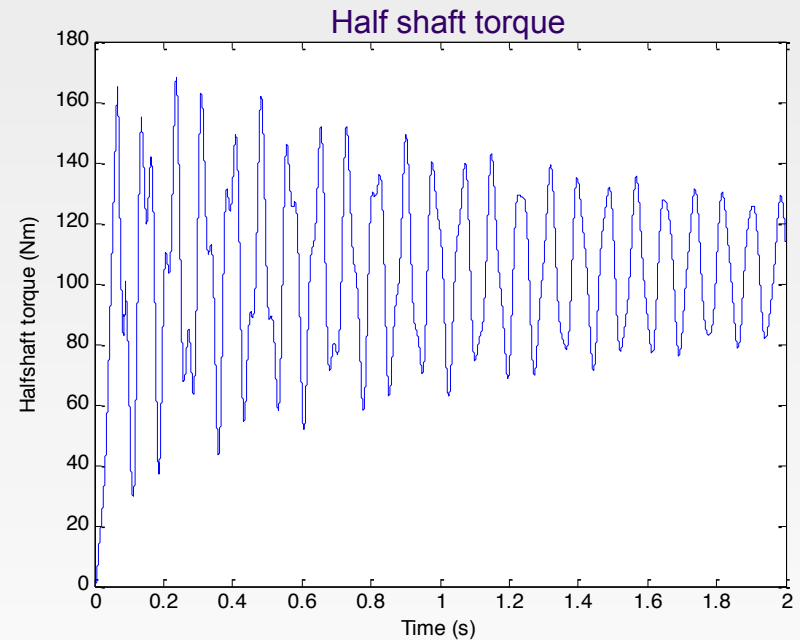
Shuffle mode

Modelling and simulation

Example results for RWD driveline with open differential on
low/low split- μ and high/low split- μ
(non-linear relaxation length tyre model)



High/low split- μ



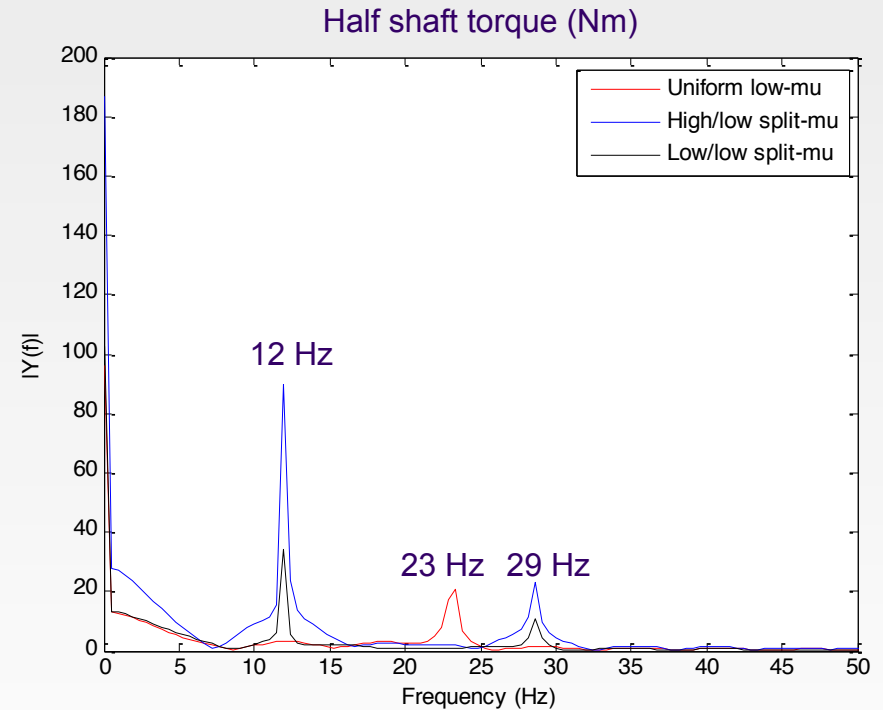
Low/low split- μ

Modelling and simulation

Frequency domain results for RWD driveline with open differential on uniform low- μ , low/low split- μ and high/low split- μ (non-linear relaxation length tyre model)

Original results by linearisation of non-linear model

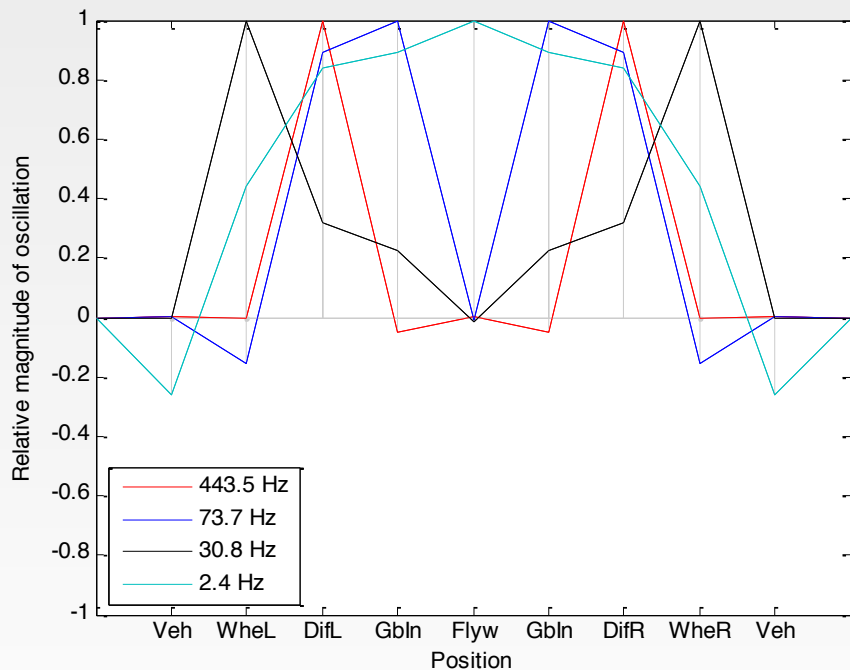
Model	Relaxation length	
Mode	Damping ratio	Damped freq (Hz)
6	0.0172	443.5
5	0.0071	226.8
4	0.0764	73.7
3	0.0081	30.8
2	0.0032	20.6
1	0.0159	2.4
0	0.0000	0 (RB)



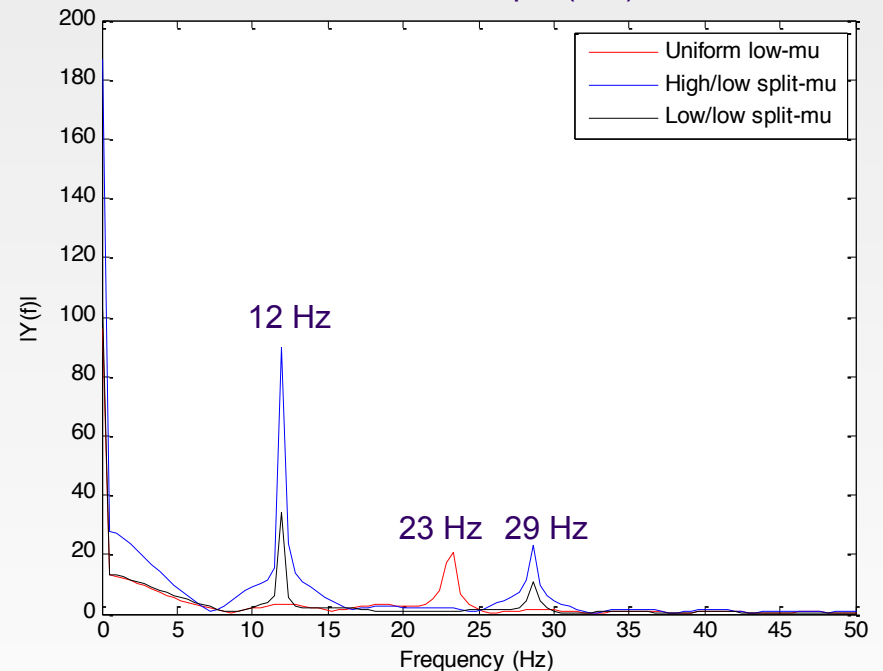
Modelling and simulation

Frequency domain results for RWD driveline with open differential on uniform low- μ , low/low split- μ and high/low split- μ (non-linear relaxation length tyre model)

Symmetric modes by linearisation

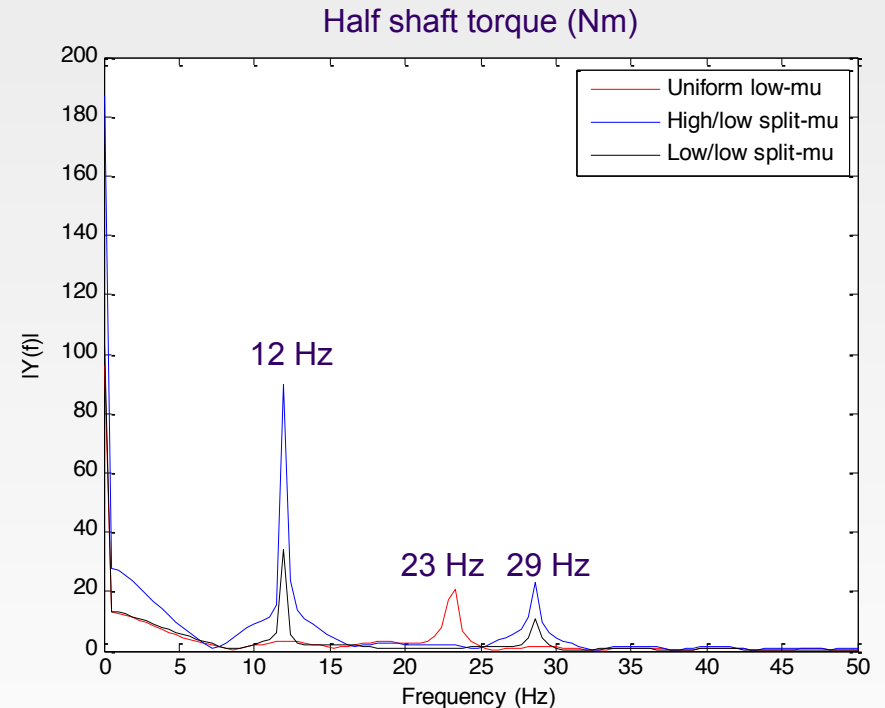
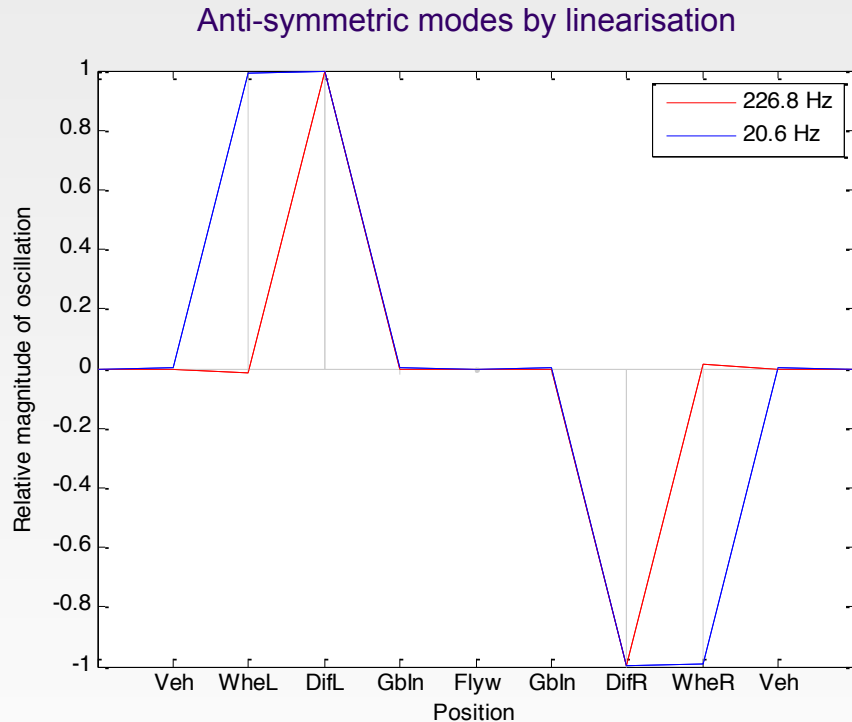


Half shaft torque (Nm)



Modelling and simulation

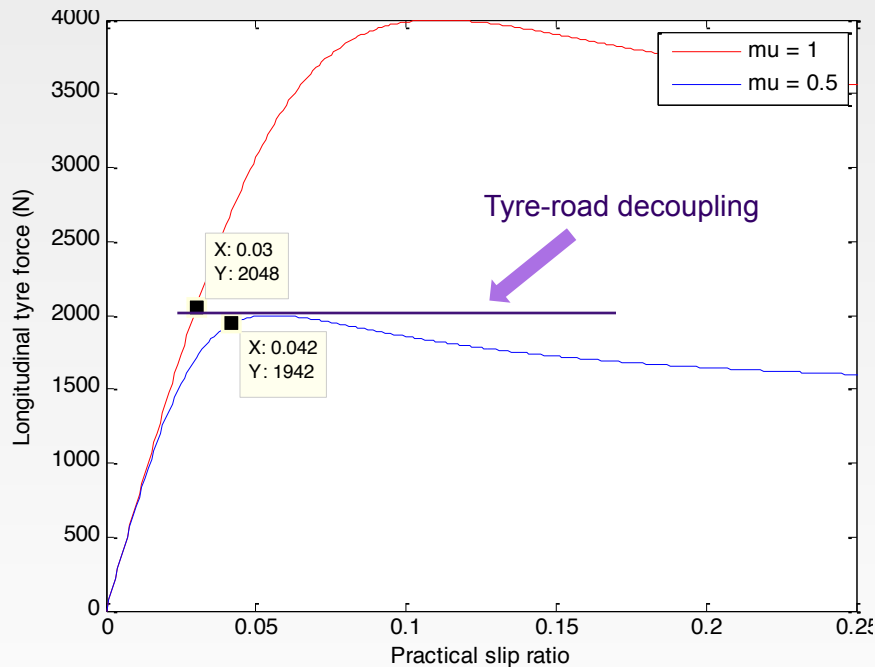
Frequency domain results for RWD driveline with open differential on uniform low- μ , low/low split- μ and high/low split- μ (non-linear relaxation length tyre model)



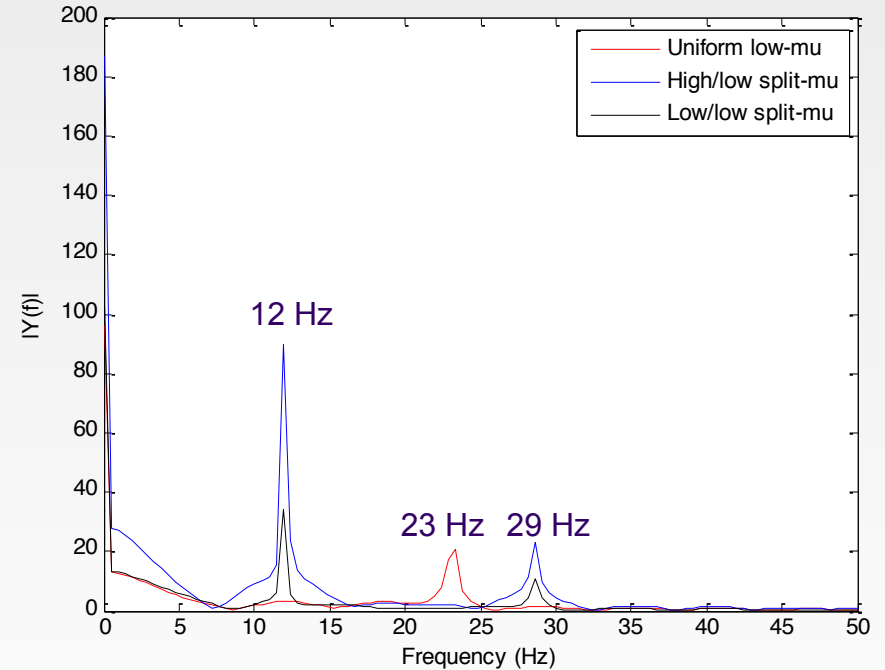
Modelling and simulation

Example results for RWD driveline with open differential on uniform low- μ , low/low split- μ and high/low split- μ (non-linear relaxation length tyre model)

A case for partial tyre-road decoupling



Half shaft torque (Nm)

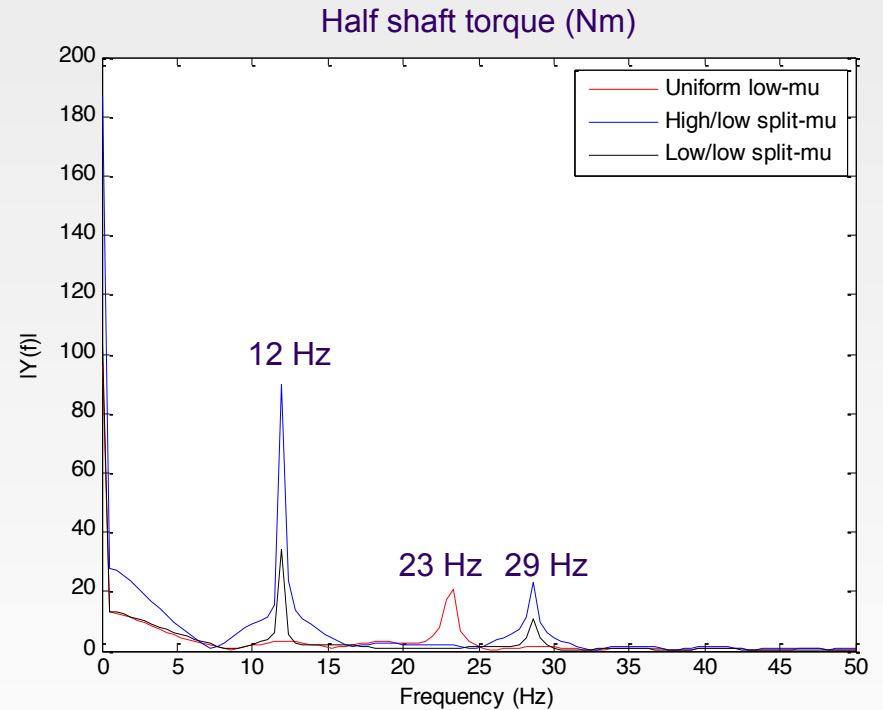


Modelling and simulation

Frequency domain results for RWD driveline with open differential on uniform low- μ , low/low split- μ and high/low split- μ (non-linear relaxation length tyre model)

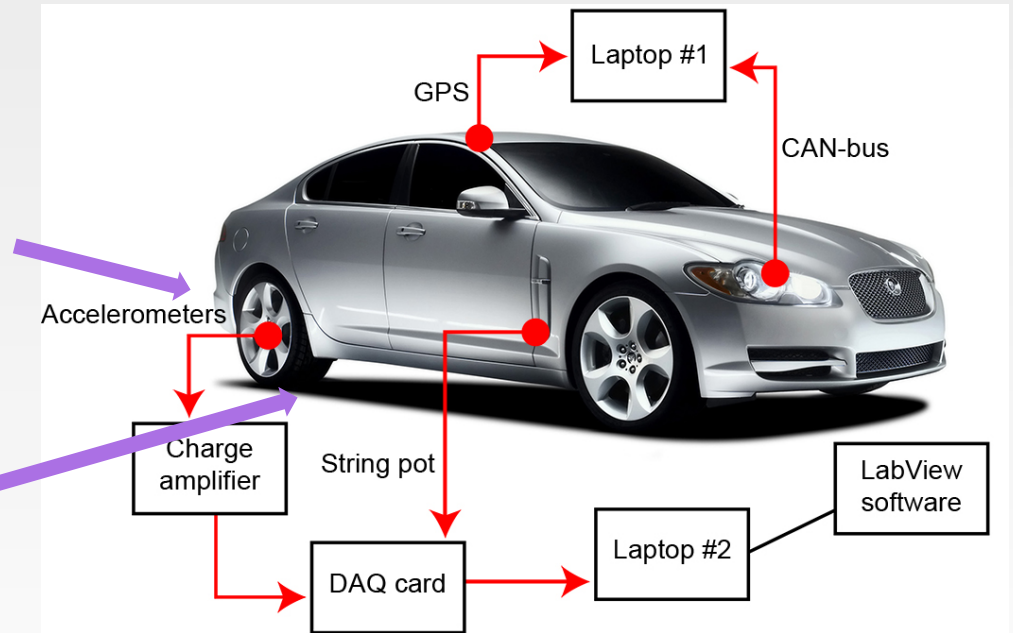
Linearisation using the concept of full/partial decoupling

Model Mode	Wheels fully decoupled from road		One wheel coupled to road	
	Damping ratio	Damped freq (Hz)	Damping ratio	Damped freq (Hz)
6	0.0172	443.5	0.0172	443.5
5	0.0071	226.8	0.0071	226.8
4	0.0769	73.6	0.0766	73.6
3	0.0081	23.2	0.0071	28.6
2	>1	0.0	0.0033	12.0
1	0	0.0	0	0.0
0	0	0.0	0	0.0



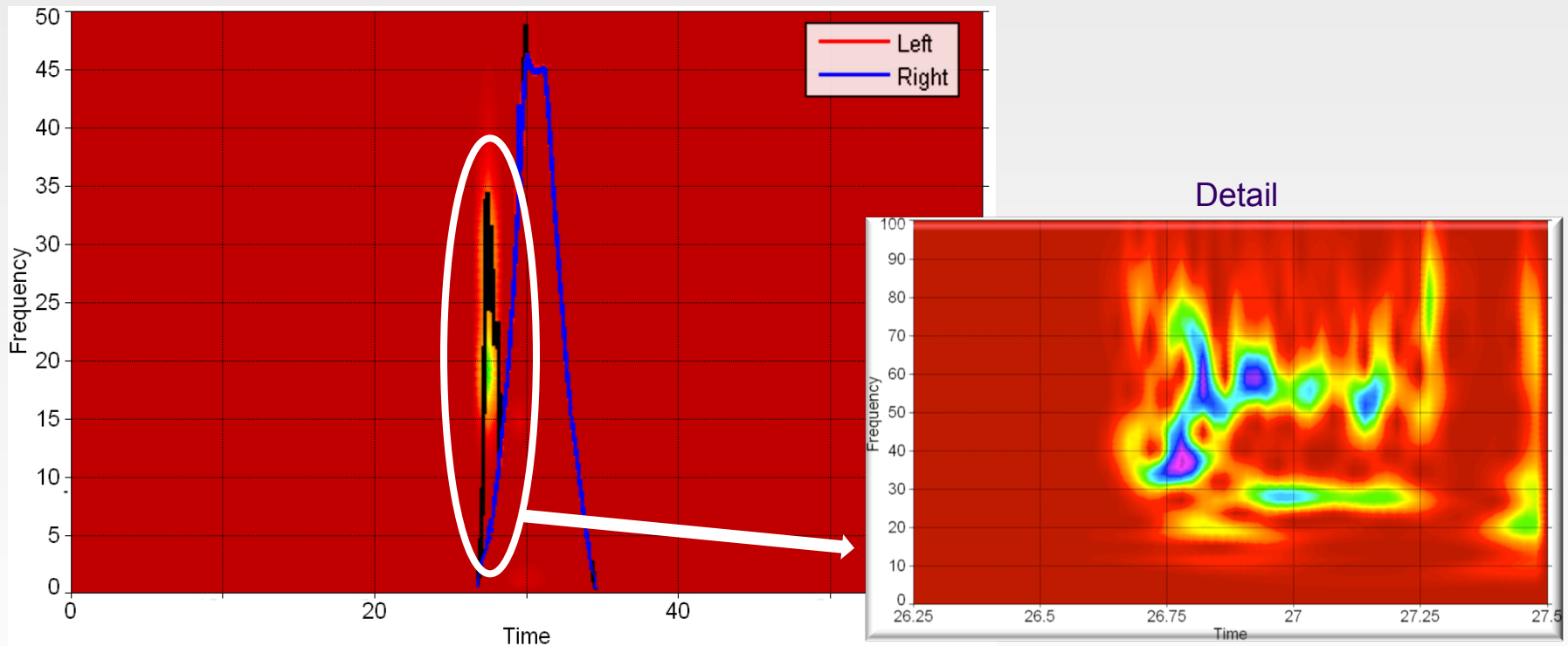
Experimental investigation

Traction tests carried out on split- μ surfaces



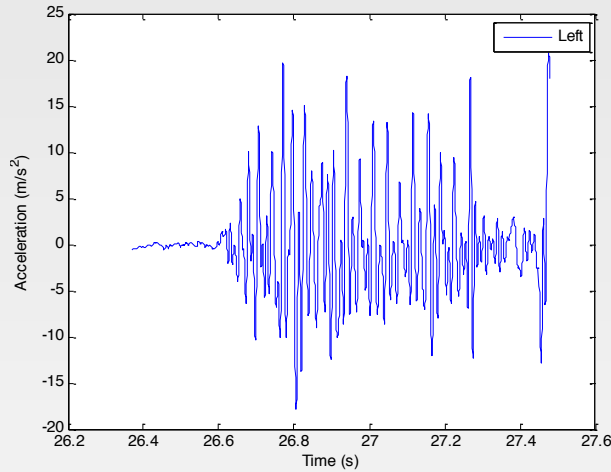
Experimental investigation

Wheel speeds superimposed on a wavelet graph of measured vibration on wheel hub (left wheel on low- μ surface)

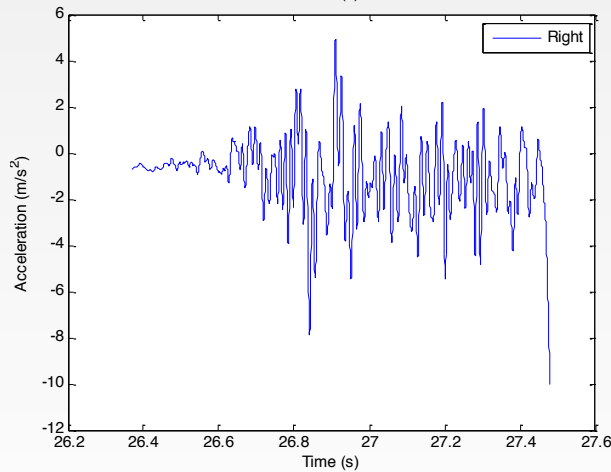
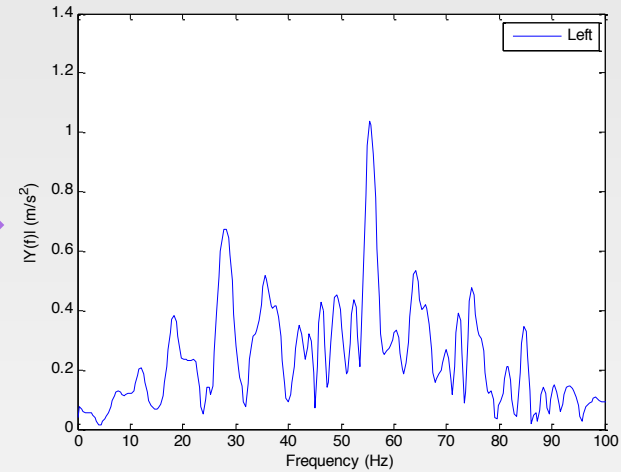


Experimental investigation

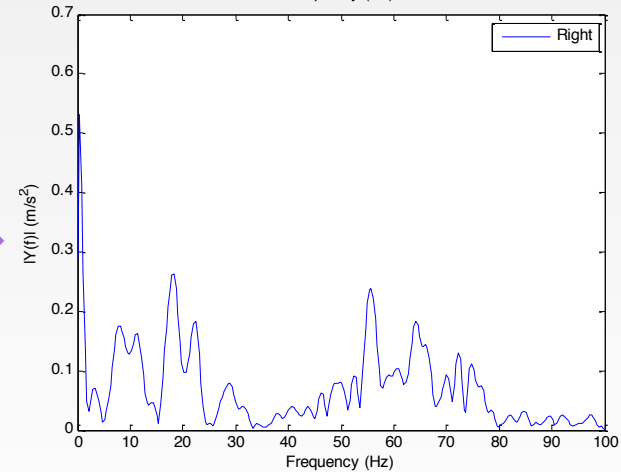
Acceleration traces measured at the wheel hubs



FFT
→

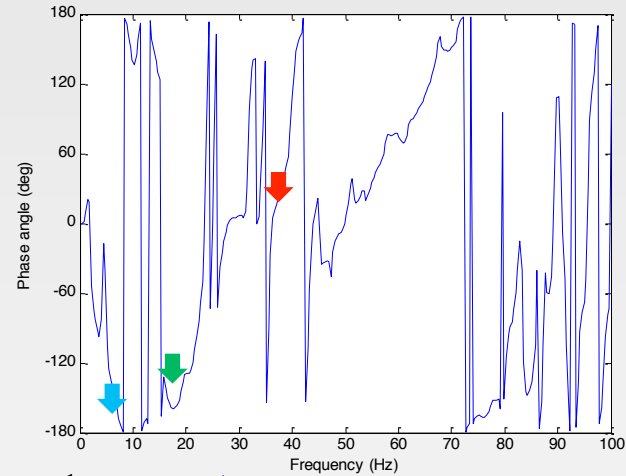
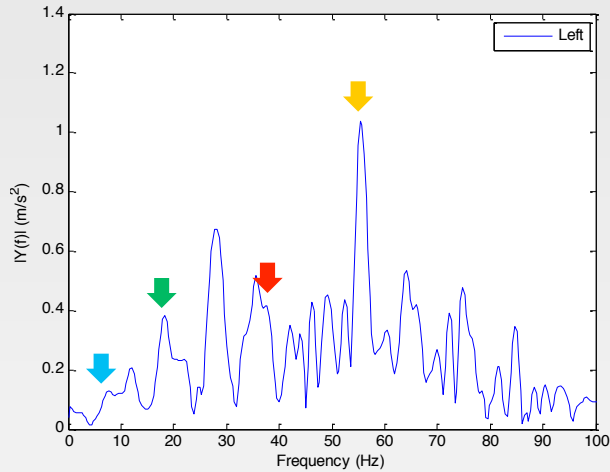


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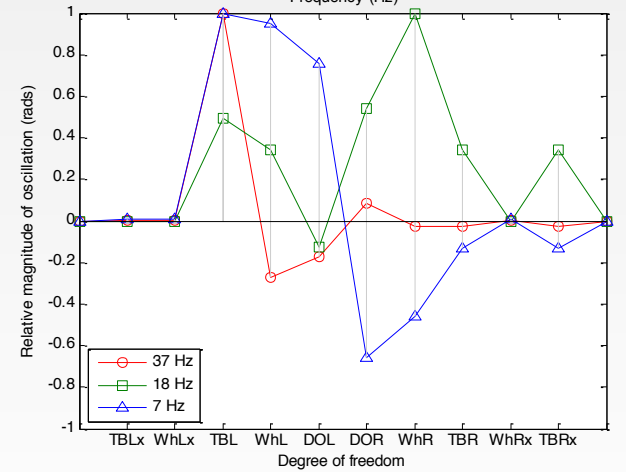
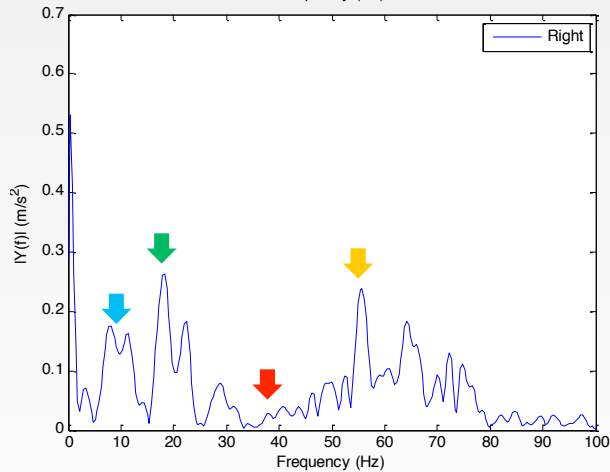


Experimental investigation

Accel. on low- μ side

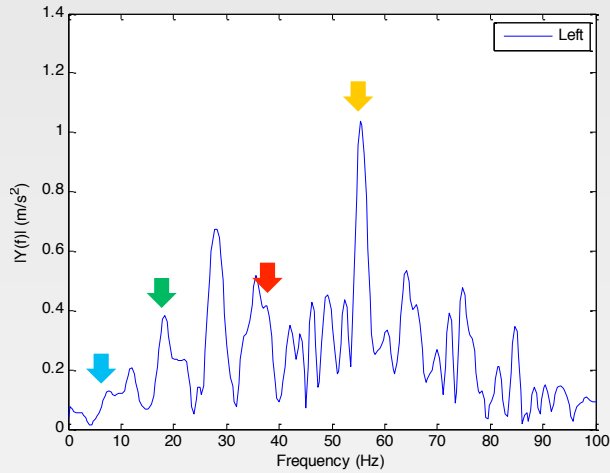


Accel. on high- μ side

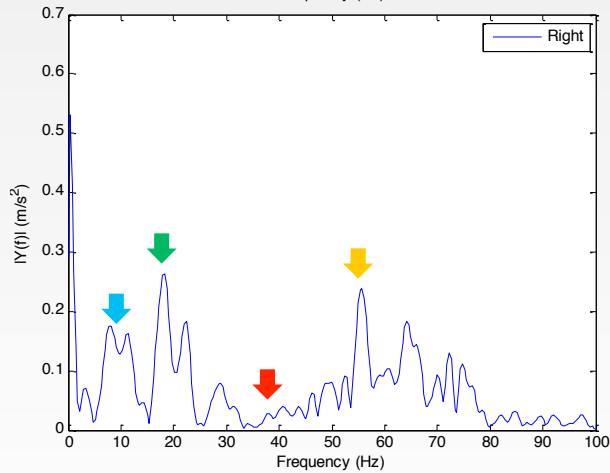


Experimental investigation

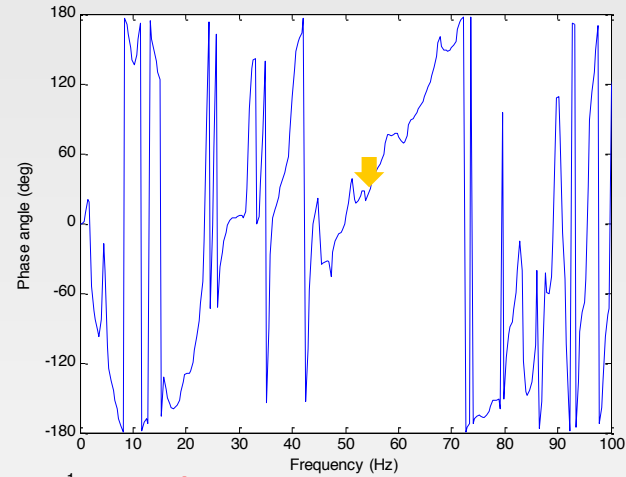
Accel. on low- μ side



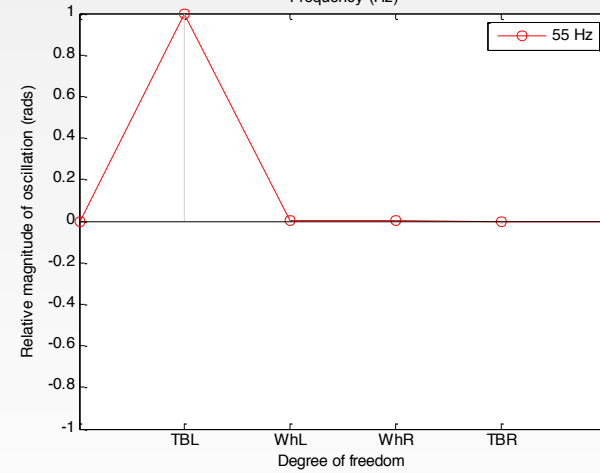
Accel. on high- μ side



Phase angle



Eigenvectors



Concluding remarks

- a) Steady-state tyre models cannot accurately predict the shuffle response - a flexible connection between the rim and the road is essential
- b) The tyre-road interface largely determines the damping of the lower frequency modes of the driveline, up to approx. 30 Hz
- c) The above damping is forward-speed dependent, with the dependency reducing as the frequency of the mode increases
- d) Frequency migration on split- μ surfaces can be predicted via the notion of tyre-road decoupling
- e) A structural tyre model including in-plane torsional and translational modes is essential in order to capture the full extent of important interactions
- f) Acceleration measurements at the wheel hubs can provide an indication of driveline response and assist with model validation

Thank you for your attention