The role of the tyre in traction-induced driveline vibrations

By
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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

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
Models implemented:

a. Manual RWD driveline with open differential
b. RWD driveline with auto transmission/torque converter
c. 4WD driveline with manual transmission coupled with 6 DOF vehicle model + suspension kinematic model
Modelling and simulation

Tyre modelling

Models implemented:

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

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

<table>
<thead>
<tr>
<th>Model</th>
<th>Torsional spring</th>
<th>Magic Formula</th>
<th>Relaxation length</th>
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<tr>
<td></td>
<td>Damping ratio</td>
<td>Damped freq (Hz)</td>
<td>Damping ratio</td>
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<td>0.0071</td>
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<td>0 (RB)</td>
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</table>

**Forward speed: 0.5 m/s**

**Forward speed: 5 m/s**

Shuffle mode

[University Logo]
Modelling and simulation

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

<table>
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Modelling and simulation

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

Symmetric modes by linearisation

Half shaft torque (Nm)

Relative magnitude of oscillation
Modelling and simulation

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

Anti-symmetric modes by linearisation

Half shaft torque (Nm)

226.8 Hz
20.6 Hz
12 Hz
23 Hz
29 Hz
Modelling and simulation

Example results for RWD driveline with open differential on uniform low-\(\mu\), low/low split-\(\mu\) and high/low split-\(\mu\) (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)

<table>
<thead>
<tr>
<th>Model</th>
<th>Wheels fully decoupled from road</th>
<th>One wheel coupled to road</th>
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Linearisation using the concept of full/partial decoupling

Half shaft torque (Nm)

12 Hz

23 Hz 29 Hz
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-$\mu$ surface)
Experimental investigation

Acceleration traces measured at the wheel hubs

FFT
Experimental investigation

Accel. on low-µ side

Accel. on high-µ side

Phase angle

Eigenvectors
Experimental investigation

- Accel. on low-µ side
- Accel. on high-µ side
- Phase angle
- Eigenvectors

Degree of freedom
Relative magnitude of oscillation (rads)
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-$\mu$ 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