



Investigating Vehicle Dynamic Effects of Passive and Active Limited Slip Differentials.

Sean Doyle

Mark Sandford

Wales Institute for Science & Art

MSc Motorsport Engineering

Introduction

A crucial component within a vehicle drivetrain is the differential. For performance benefits, open differentials are often replaced with a far superior limited slip differential (LSD). However, many different types of LSDs are available today, each responding and affecting vehicle handling differently. With such a crucial component of the drivetrain often neglected in vehicle dynamics literature, the author of this project felt the need to investigate this subject to fill in gaps within industry knowledge.

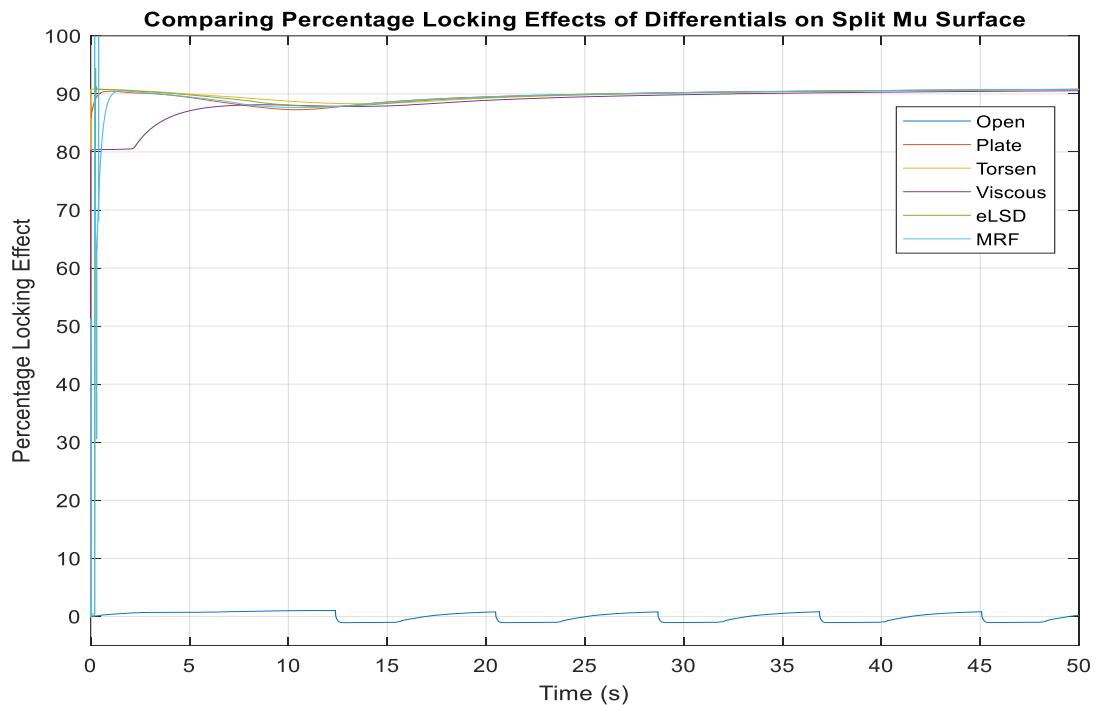
Differential Principles

The purpose of an open differential is to transmit engine power and torque to the drive wheels, whilst allowing wheels to rotate at different speeds when cornering [1]. An LSD is often used instead of an open differential in high performance applications such as motorsport where these devices are able to transfer torque to higher traction wheels, and limit tyre slip. When considering LSDs, two main categories exist, passive and active. Passive devices are purely mechanical in operation, whilst active devices utilise vehicle sensor data and control systems to manage the LSDs output [2]. This project investigates the following LSDs: clutch pack, viscous coupling, torque sensing (‘Torsen’) and electronic limited slip differential. Finally, a more obscure LSD referred to as a magnetorheological fluid LSD is also tested.

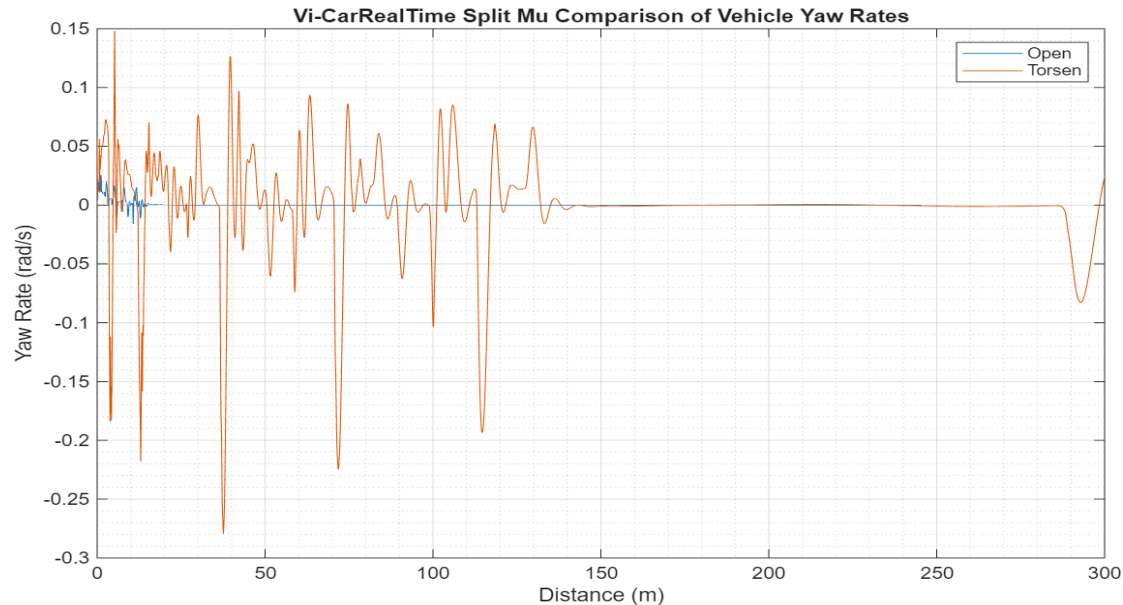
Testing Scenarios

The following virtual testing was conducted to investigate LSDs:

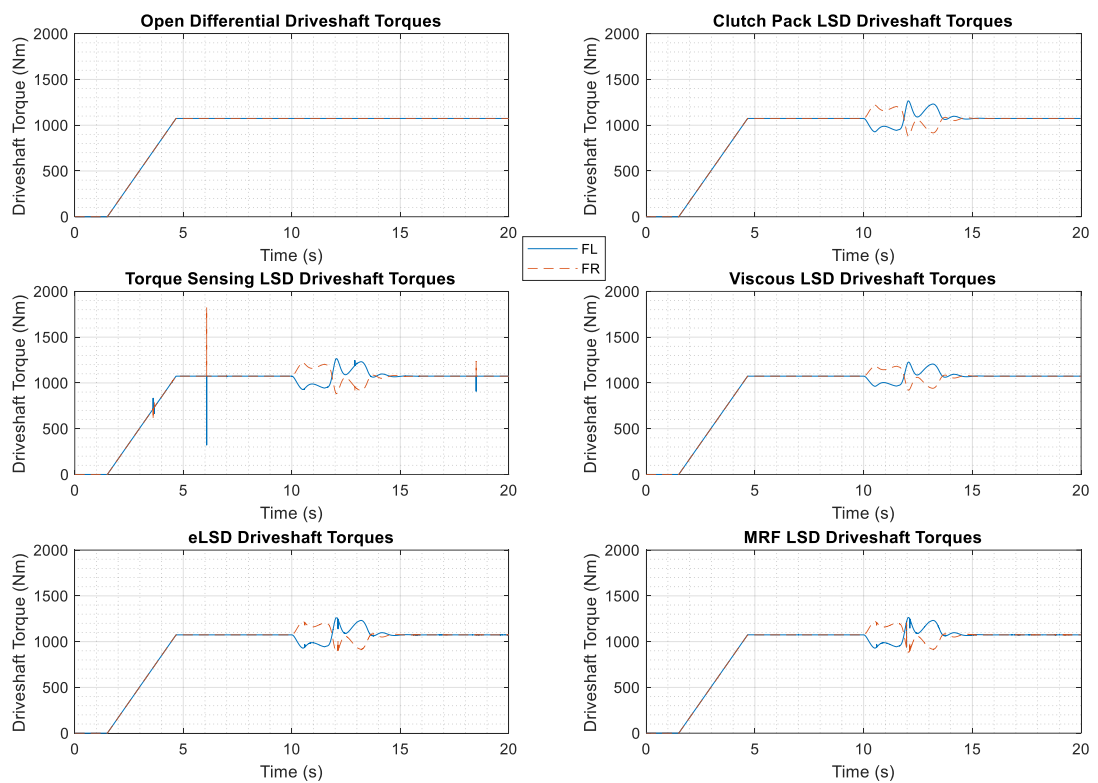
- **Split mu** – left surface ice, right surface dry tarmac.
- **Lane change** manoeuvre.
- **Ramp steer** manoeuvre.



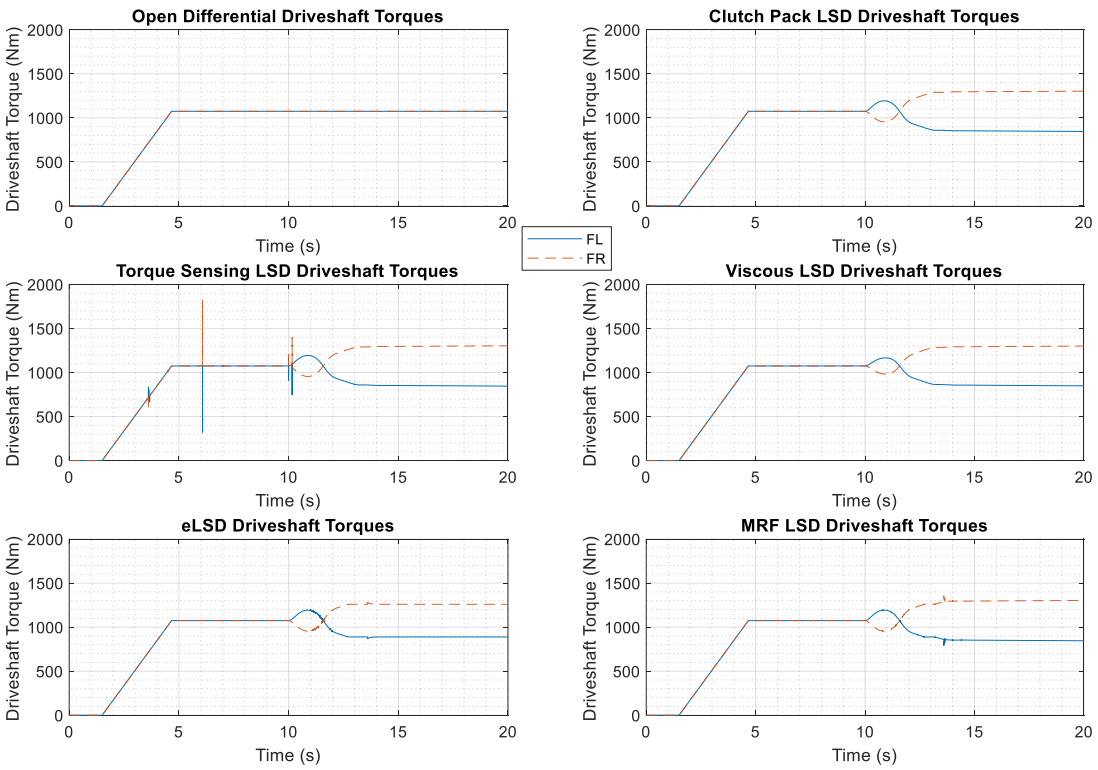
Split Mu results demonstrating percentage locking effect of each differential.



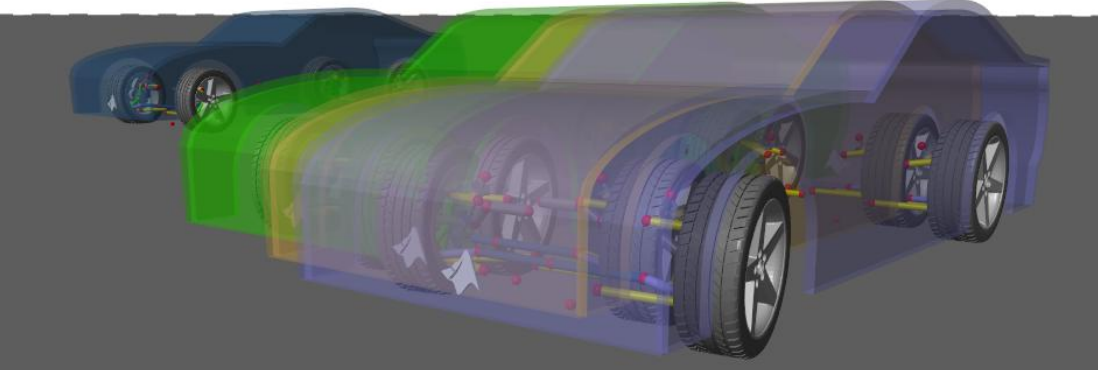
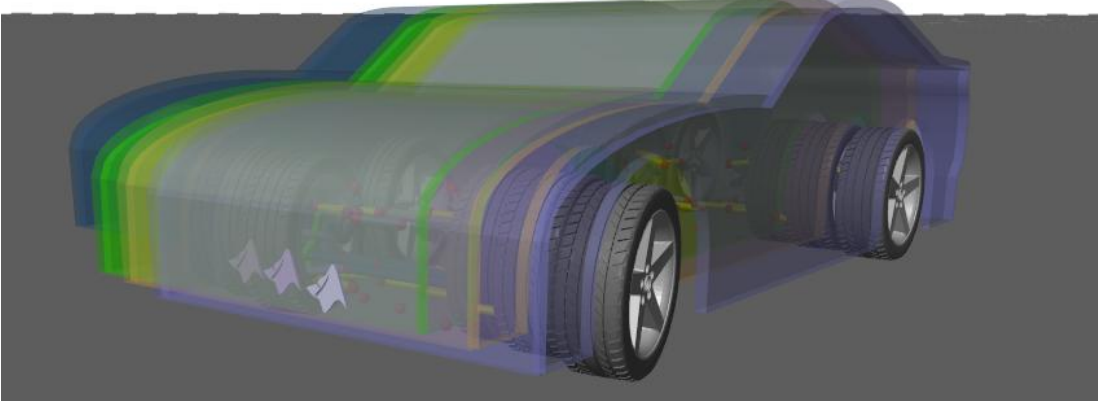
Validation results for split mu scenario, demonstrating vehicle yaw rates for torque sensing and open differentials.



Driveshaft torque results for Lane change manoeuvre.



Driveshaft torque results for ramp steer manoeuvre.



Ramp Steer Manoeuvre Demonstrating Open (Blue), Torsen (Orange), Viscous (Purple) and eLSD (Green) differentials.

Results

The multibody and driveline simulation results revealed significant torque steer occurring during the split mu event. This is due to front wheel drive configurations impacting vehicle steering with transferring/biasing of up to to 90% torque to the wheel with most traction (particularly for the instant reaction of the torque sensing device [3]). This causes large yaw moments to act on the vehicle suddenly and uncontrollably for most human drivers. On the contrary, an LSD can propel a vehicle at nearly three times the velocity of an open differential when on a split mu surface. Data demonstrates the viscous LSD is a more controllable device, increasing driver reaction times with the wheel speed difference triggering mechanism. The eLSD and clutch pack device respond in a similar manner to the torque sensing device but with small delays in locking response. Thus giving the driver a longer reaction and response time. Further tuning of active devices would give added benefits to vehicle controllability and predictability.

Conclusion

While no LSD type is universally superior, each offers distinct advantages. The clutch pack LSD nears torque-sensing performance with added controllability. The eLSD stands out for its adaptability in controller design, while the viscous LSD is more user-friendly. Results depend on vehicle type, application, surface conditions, and driver skill. Motorsport users should consult regulations, as some LSDs may be restricted in certain series.

References

[1] Crouse, W. & Anglin, D., 1983. *Automotive Manual Transmission and Power Trains*. 6th ed. United Kingdom: McGraw-Hill.

[2] Palazzolo, J., 2009. *High-performance Differentials, Axles & Drivelines*. United Kingdom: CarTech.

[3] Bruls, O., Duysinx, P., Poulet, N. & Virlez, G., 2011. *Simulation of Differentials in Four-Wheel Drive Vehicles Using Multibody Dynamics*, Washington: Department of Aerospace and Mechanical Engineering.