LONGITUDINAL PERFORMANCE OPTIMIZATION OF RWD VEHICLE

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Summary: The longitudinal performance of a vehicle is the ability to achieve the highest longitudinal acceleration on the given road surface and tyres. The engine is capable of high torque delivery especially in low vehicle speed. A pre-emptive controller has been deployed to control the torque delivery where tyres are being used in their peak friction area.

Key words: engine, longitudinal acceleration, tyre, road

INTRODUCTION

Historically the torque output of a spark ignited powertrain was linked only to the angle of driver's demand pedal. A modern performance vehicle is restricted by several other boundary conditions that directly influence the torque output.

Performance vehicles are being optimized to be fast and powerful in terms of speed and acceleration. Specific tyres with high friction capabilities are used to for best traction, however, this can only be true if the tyre is used in its working range. This leads to deployment of a strategy that controls the engine torque output to assure the tyres are used on their limits.

1. TRACTIVE TORQUE

1.1 Road contact

The aim to optimize the torque output to the maximum vehicle's acceleration is limited by the maximum force the tyres can transfer through the contact patch on the base surface. The main variables are the friction properties and the normal load on the tyre. The maximum tractive force can be expressed as:

$$F_x = \mu \cdot W \tag{1}$$

1.1.1 Tyre load

The normal load is defined as a sum of perpendicular components of the forces acting on the tyre with respect to the contact patch.

- Static load
- d'Alembert inertial force
- Aerodynamic load
- Grading resistance

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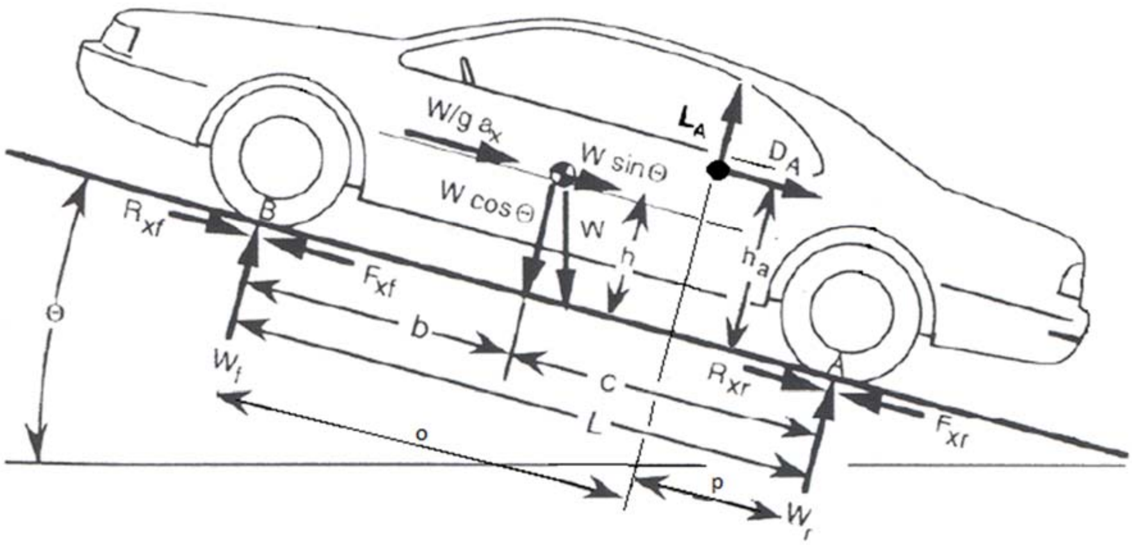
- Longitudinal weight transfer
- Lateral weight transfer
- Rolling resistance



Pic. 1 – Vehicle forces

Source: GILLESPIE,T.D. (1)

For the purposes of this experimental optimization only the major components are considered with the others assumed to be negligible.

Static load

$$W_{r\_s} = m \cdot g \cdot \frac{b}{L} \tag{2}$$

d'Alembert inertial force

$$W_{r\_ax} = m \cdot a_x \cdot \frac{h}{L} \tag{3}$$

Aerodynamic load

$$L_{Ar} = \frac{1}{2}\rho \cdot SC_z \cdot v^2 \cdot \frac{o}{L} \tag{4}$$

Grading resistance

$$W_{r\_h} = m \cdot a_z \cdot \frac{b}{L} \tag{5}$$

1.1.2 Friction

The tyre's friction properties can be drawn as friction ellipse with separate coefficients for lateral and longitudinal forces. The location on friction ellipse is calculated at every given moment. This is then compared to the maximum estimated tyre potential in both lateral and longitudinal direction which results in maximum tractive force to be estimated.

$$F_{xr} = \sqrt{\left(1 - \frac{\mu_y^2}{\mu_{ymax}^2}\right) \cdot \mu_{xmax}^2 \cdot W_r} \tag{6}$$

1.2 Tractive torque

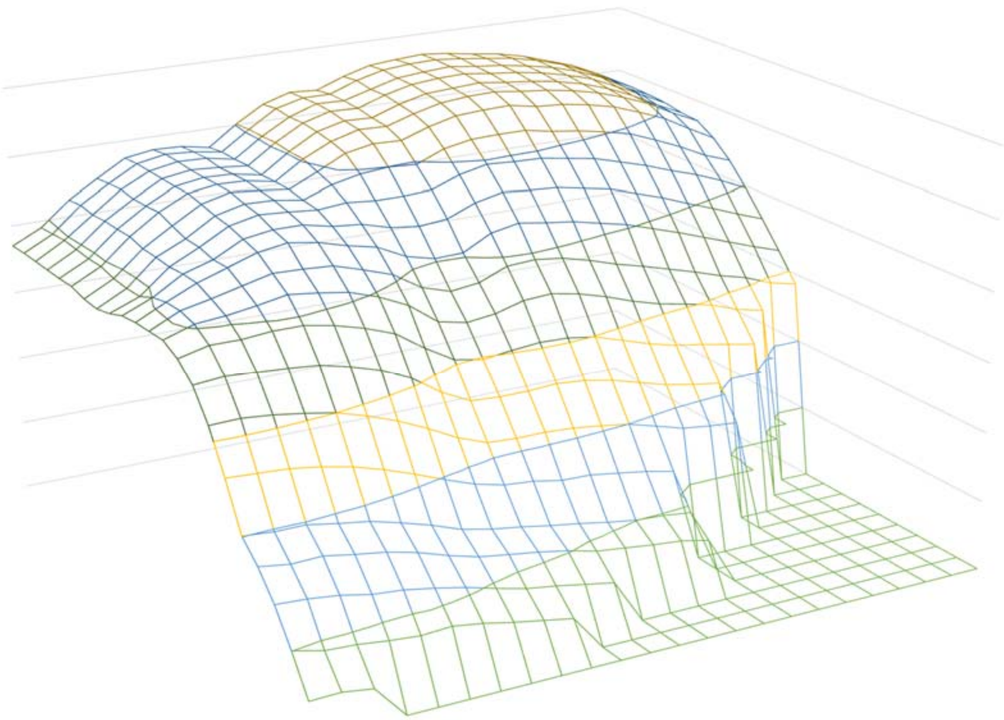
The rear axle drives two separate wheels through limited slip differential. This assumes the tractive force is being delivered equally on both wheels. The tractive torque per rear axle is then given as.

$$\tau_r = F_{xr} \cdot r \tag{7}$$

2. TORQUE LIMIT

Engine torque limit is applied with the aim to deliver the highest possible longitudinal acceleration of the vehicle whilst a higher torque demand is requested from the driver.

Engine torque is modelled based on the real-time engine variables which is then used in feedforward controller to apply the limitation at any given working point of the engine.



Source: Author

Fig. 1 – Engine Torque model

3. STRATEGY

3.1 Engine torque model verification

The validation of the engine torque is necessary part of the functionality of the entire strategy. The vehicle was equipped by a precision torque meter on the input shaft of the gearbox. Necessary calibration of the measurement was performed prior the running of the engine.

The measurements were taken under normal running conditions of the vehicle, however, with the goal to capture the entire working range of the engine. The gathered data are compared against the real-time model of the engine torque output. Necessary adjustments are made to the model to achieve desired correlation with the real engine data. The resultant data are plot below.

The modelled prediction shows higher torque values especially in lower RPM range. In this area the engine is in transient conditions under fast acceleration hence the higher error between the modelled and real states.

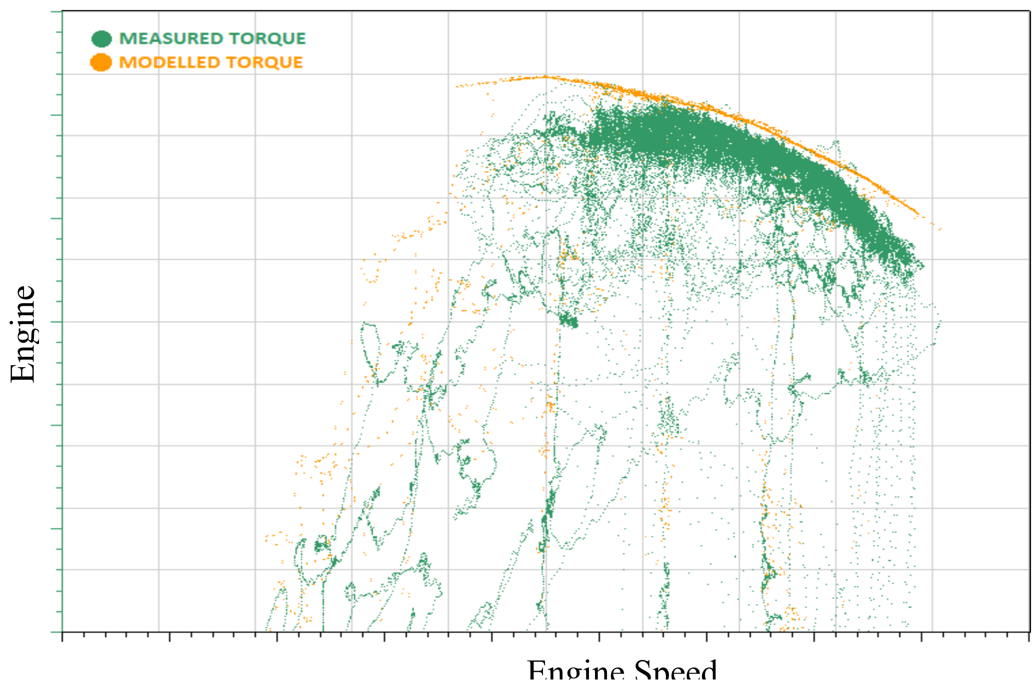


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Fig. 2 – Engine Torque Validation

3.2 Constant slip acceleration

The highest transferable longitudinal force is at a specific slip ratio with a small peak around it. Hence to gain the highest acceleration the controller is tuned to limit the engine torque output to keep the slip ratio constant around the defined point given by tyre properties.

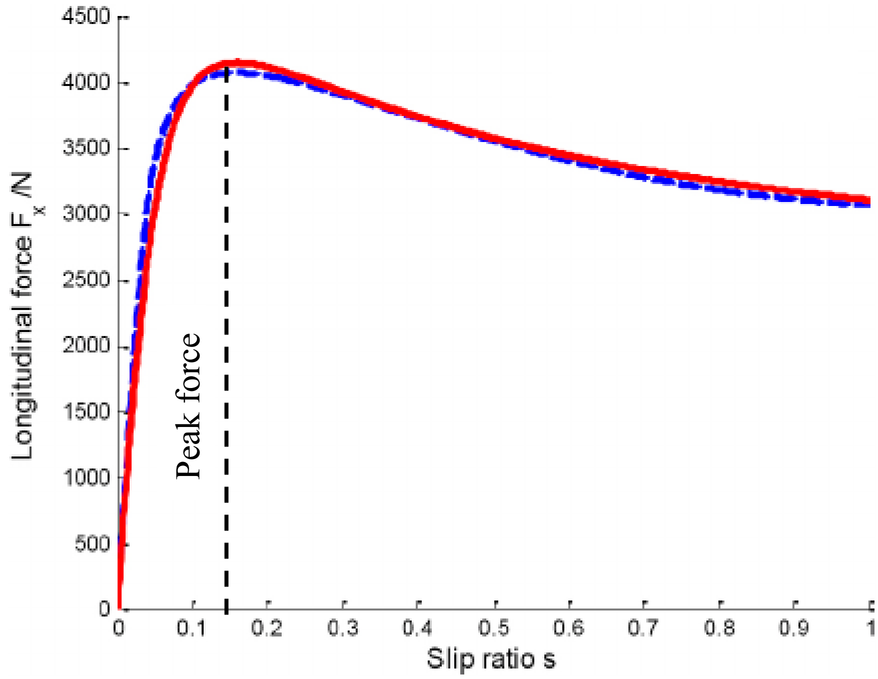

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Fig. 3 – Engine Torque Validation

The final functionality is shown below where the vehicle is accelerating with combined tyre load from lateral, cornering, and longitudinal directions. The torque limitation is being applied to the engine control strategies which results in constant rear wheels slip ratio.

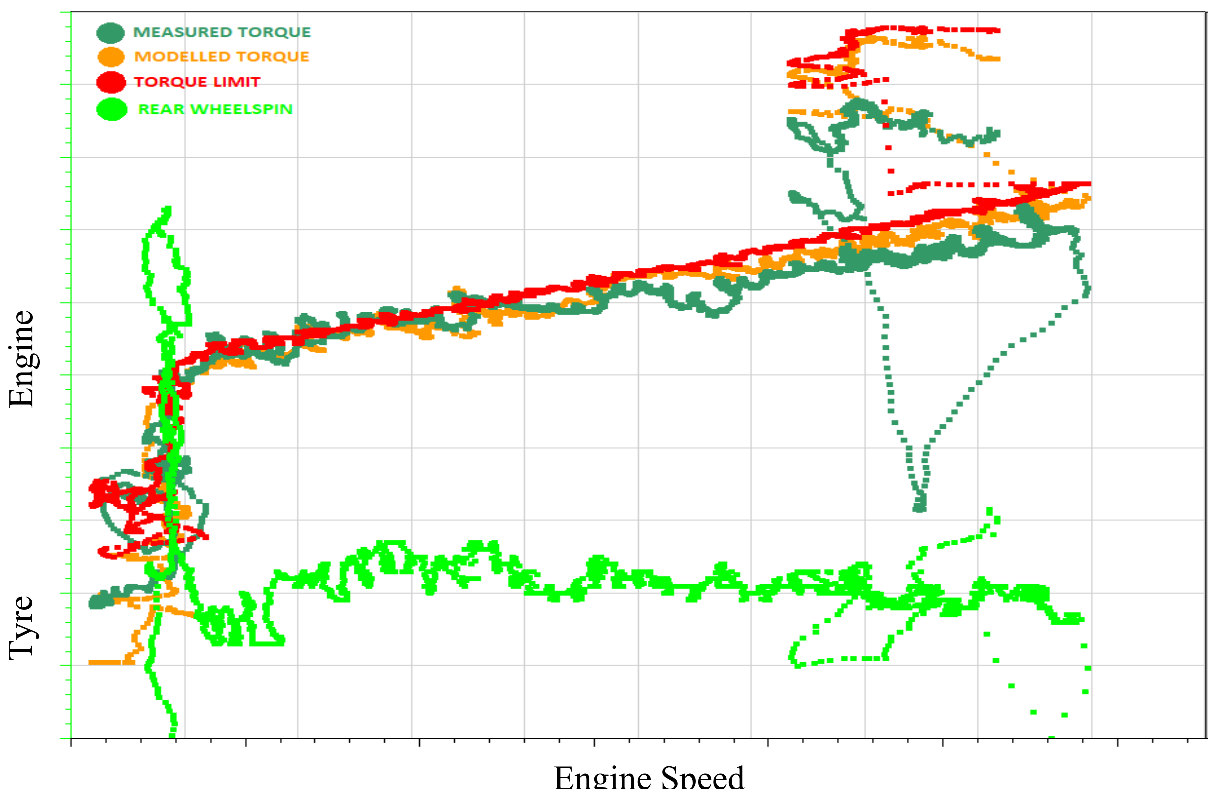

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Fig. 4 – Engine Torque Limit applied

CONCLUSION

The longitudinal performance optimization was studied in this paper. The best longitudinal acceleration could be achieved by limiting the engine torque output to drive the tyres in the highest longitudinal force capabilities. The tractive torque model was created, based on the tyre friction ellipse with tuneable friction coefficients in both lateral and longitudinal directions. Together with engine torque output model the engine was limited to the available tractive torque. The overall strategy functionality provides the ability to accelerate with constant slip ratio which magnitude can further be adjusted by the tyre friction coefficients.

REFERENCES

(1) GILLESPIE,T.D. *Fundamentals of Vehicle Dynamics*, Society of Automotive Engineers, Warrendale, PA, 1992. ISBN 1-56091-199-9.

(2) PACEJKA,H.B., TAKAHASHI,T. *Cornering on uneven roads*, Vehicle System Dynamics Vol. 17 (1988), No. 7.

(3) WONG,J.Y. *Theory of Ground Vehicles*. John Wiley & sons. 2001 (3rd edition). ISBN: 0471354619

(4) BOSCH,R. *Automotive Handbook*. 5th edition. 2002. Society of Automotive Engineers (SAE). ISBN:0837612438

(5) BELL, GRAHAM A. *Four-Stroke Performance Tuning 4th Edition*. Sparkford : Haynes Publishing, 2012. ISBN: 9780857331250.

(6) *Comparison of engine simulation software for development of control system*. CHAN, KinYip, et al. 2013: 5, s.l. : Modelling and Simulation in Engineering, 2013.