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Tuning Vehicle Dynamics & Control Functions For Coach

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Abstract: The objective of this work is summarizing three parameter tuning efforts for enhanced vehicle dynamics performance of diesel coaches. The first one is tuning the brake controller ABS algorithm parameters, such that during straight line split μ ABS braking, the steering applied by the driver to hold the vehicle straight, does not exceed the level indicated in ECE R13 regulation. The second one is tuning the brake module traction control (ASR) parameters such that ASR is initialized earlier; at a lower tire slip threshold, to avoid unnecessary successive electronic stability control (ESP) interventions, during steering maneuvers on low μ. The last one is tuning the gear down-shift schedule of the automated manual transmission of the vehicle (that is within the central vehicle ECU) during retarder lever braking, such that the engine brake is utilized more efficiently. Vehicle test results are presented for each case, comparing the default parametrization with the tuned one, emphasizing the benefits that come with fine tuning the controller parameters.
Keywords: ABS, split μ, ASR, ESP, engine brake, coach

1. INTRODUCTION

Keeping the vehicle straight during braking on a split-μ surface is the main objective of the driver. For this purpose, the driver typically steers the vehicle towards the low μ side during braking, as illustrated in Figure 1.

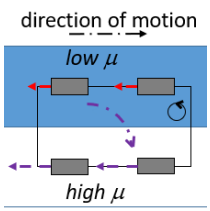


Figure 1. The unintentional yawing motion of the vehicle, due to the higher braking forces in the high μ side, and the driver applying steering action towards the low μ side to keep the vehicle straight.

There are automatic steering controllers in literature that work in coordination with ABS control for achieving this task [1-5]. In [1], an integrated control system for vehicle braking and steering has been

optimally designed to achieve the safe braking on split-μ roads. Using the stability index obtained by the phase plane analysis, fuzzy logics have been defined to determine weights of each control input in various conditions. The simulation results show that the proposed integrated control system leads to improved directional stability. In [2], experimental results on normal split-μ and 'checkerboard' roads have proven that the proposed feedback-feedforward steering controller can control the vehicle follow a lane centerline and suppress vehicle sway and system overshoot effectively. A receding horizon linear quadratic regulator (LQR) is utilized to design the optimal feedback part, and the final value theorem is utilized to compute the steady-state error, and the feedforward steering input is designed to eliminate this error. In [3], a coordinated controller of brake and steer by wire is proposed for autonomous emergency braking on split-μ roads. Hardware-in-the loop tests are performed to evaluate braking efficiency and vehicle stability under different conditions. The coordinated controller could greatly improve vehicle stability, reducing the yaw rate by 90% as well as over 60% of yaw angle and side slip angle, in contrast to the driver model and traditional ABS controller. In [4], by constructing a flexible control transfer mechanism based on the vehicle state, the active steering algorithm is used to improve the path tracking algorithm at the beginning of the braking process. Dynamic stability and path tracking accuracy of the emergency braking process on the split-μ road are optimized. This is achieved through application of an LQR algorithm for the path tracking algorithm to restrain the violent fluctuation of the front wheel angle. [5] is a recent work, proposing a new coordinated steering – braking algorithm on the split-μ surface, that uses (i) a feedforward steering angle from a lookup table and (ii) a high-friction braking controller that reduces excessive yaw torque. The proposed controller performs well in high-fidelity simulations, reaching the maximum deceleration with minimal path deviation and quick yaw rate reduction. Additionally, automating steering improves stopping distance compared to an emulated human driver.

In the first part of this work, rather than focusing on an autonomous steering controller during braking on the split-μ surface, whose recent literature is summarized above, the braking of a non-autonomous; i.e. conventional vehicle is considered. The vehicle whose brake ECU's ABS algorithm was tuned, is a three axle coach (whose short technical specifications are given in Table 1), such that the steering applied by the driver to the vehicle to hold it straight does not exceed the levels stated in the ECE R13 regulation, Annex 13 [6].

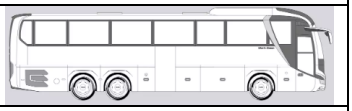
The second tuning effort is for the traction control (ASR) tire slip initialization thresholds, during steering maneuvers on low μ. It is well-known that the ASR is triggered as the driven axle's tire slip exceeds certain thresholds on low-μ surfaces, depending on various factors such as vehicle speed, and lateral acceleration [7]. These tire slip initialization thresholds should be tuned cautiously [8]. With this background, the second part of this work focuses on ASR activation for steering maneuvers on low μ for the two axle coach (whose short technical specifications are given in Table 1), such that unnecessary successive ESP yaw control interventions are avoided.

The third, and final tuning effort, is for the gear down shift schedule of the 12 speed transmission of the coach. There are countless examples of gear shifting optimization studies in literature, considering fuel economy of commercial vehicles [9, 10]. However, this section of this study, focuses on more efficient use of the engine brake feature [11-14]. With the knowledge that engine brake operates more efficiently at higher engine speeds, the objective of the study was tuning the gear down-shift schedules during retarder lever braking. Default parametrization vehicle test result is compared with the tuned parametrization test result, with the objective of demonstrating the benefit that comes with the tuning effort.

The organization of this study is as follows: In the next section, tuning the brake module parameters of the three axle diesel coach during ABS split μ braking, is explained. Section 3 shows test results for lowering the ASR tire slip initialization thresholds, during a steering maneuver on low μ. Section 4 is dedicated to the test results obtained after tuning the gear down shift schedule of the 12 speed automated

manual transmission of the vehicle, such that more efficient engine brake is utilized during retarder lever braking of the vehicle. The work is finished with the conclusions section.

Table 1. Short technical specifications of the two-axle and three-axle diesel coach.

	2 axle Coach	3 axle Coach
		
Engine		
Type of drive	Diesel	Diesel
Engine model	D 2676 LOH Common rail	D 2676 LOH Common rail
Bore/stroke/displacement	12,419 cm^3	12,419 cm^3
Rated output	353 kW (480 HP)	382 kW (520 HP)
Maximum torque	2450 Nm	2650 Nm
Gearbox		
12 speed semi-automatic manual gearbox	✓	✓
Vehicle dimensions		
Length/width/overall height	12,101 mm/2,550 mm/3,870 mm	13,361 mm/2,550 mm/3,870 mm
Turning circle	20,880 mm	20,960 mm
Wheelbase	6,060 mm	6,060 / 1,470 mm

2. ABS SPLIT-μ TESTING & COUNTER STEERING THE VEHICLE

ABS braking on a split-μ surface requires counter steering the vehicle towards the low-μ side, in order to keep the vehicle straight. However, there is a trade-off between how much the vehicle is steered and stopping distance. The more braking force difference there is, between the high and low μ sides, the shorter the stopping distance (better), but the higher the counter steering action. However, there is a limit on the magnitude of the counter steering action towards the low μ side, dictated by the ECE R13 regulation: 120 degrees of handwheel. The MAN internal standard is 90 degrees, on the other hand.
Figure 2 a-c-e show the vehicle test results obtained with the default parametrization, for a split-μ ABS braking maneuver with the three axle coach, with left side of the vehicle on asphalt, and right side on wet basalt surface with μ=0.1. It can be seen from Figure 2a-b (left axis) that the driver floors the brake pedal, and the brake pressures pulsate (right axis), with a higher magnitude for the high μ side compared to the low μ side, as expected. The corresponding wheel speed profiles are shown in Figures 2e-f (left axis). The difference of the tuned configuration; i.e. Figures 2b-d-f with respect to the default parametrization; Figures 2a-c-e, lies within the difference between Figures 2c and 2d: The brake force difference limit (parametrizable) between high and low μ sides of the vehicle (left axis in Figures c-d), is tuned such that it is low enough in order to avoid exceeding the counter steering limit of 90 degrees, yet high enough in order to obey the deceleration limit dictated by ECE R13. This limit is given by (Appendix 3 of Annex 13)

$$a_x > 0.75 * (4*0.1 + 0.9) / 5 = 0.20\ g \cong 1.91\ m/s^2 \quad (1)$$

where 0.9 is the high μ side (asphalt) adhesion coefficient. It can be seen that the blue curve (parametrizable) in Figure 2d is almost halved, compared to the one in Figure 2c, yielding a counter steering action in the clockwise direction, with a magnitude lower than 90 degrees (Figure 2d-right axis), compared to the one of Figure 2c-right axis (exceeding 120 degrees). This sacrifices longitudinal

acceleration, as can be observed in Figure 2f-right axis, compared to the one in Figure 2e-right axis (lower deceleration magnitude on average, with the tuned configuration). Yet the vehicle deceleration level does not go below the limiting level given by Equation 1. As a result, the tuned configuration is applied to the series production.

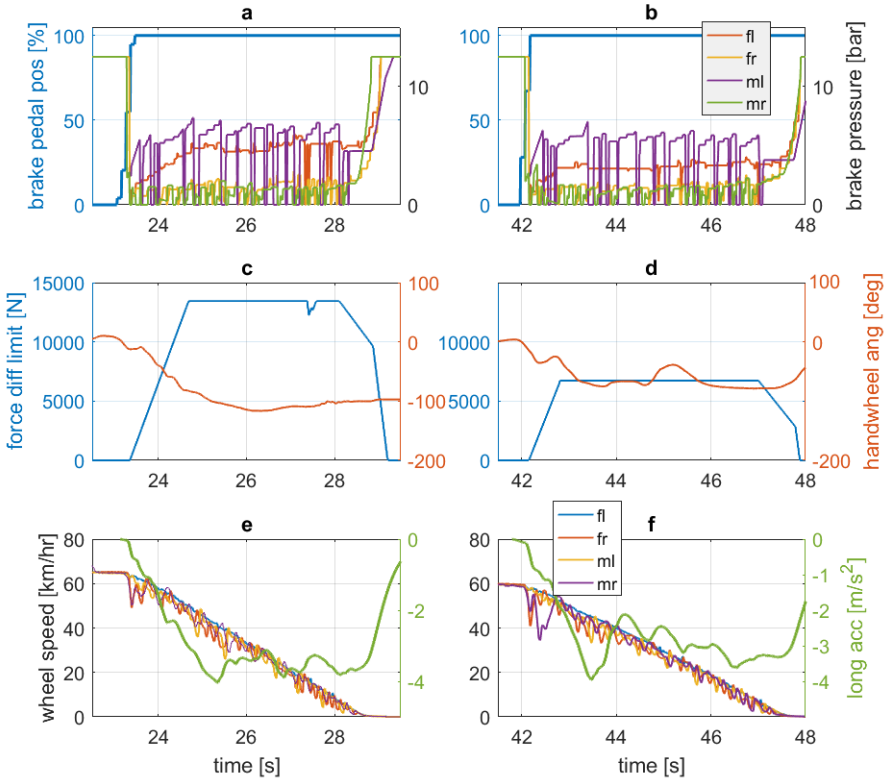


Figure 2. Top row: left axis - brake pedal position, right axis – wheel brake pressure for the front and driven axle. Middle row: left axis – the limit for the brake force difference between high and low μ sides (parametrizable), right axis – handwheel angle (negative indicating clockwise direction). Last row: left axis - wheel speeds, right axis – filtered longitudinal acceleration. a-c-e: default parametrization b-d-f: tuned. fl: front left, fr: front right, ml: middle left, mr: middle right

3. ASR INITIALIZATION THRESHOLDS FOR STEERING MANEUVERS ON LOW μ

The ASR algorithm, compares the wheel slip (by comparing the speeds of the tractive wheels versus the vehicle speed obtained by using the front wheel speeds) during traction, and applies engine torque reduction & brake intervention, if tire slip exceeds certain thresholds. The overview of the algorithm is given in [7], it is not repeated here for brevity.

Figure 3 a-c-e-g shows the vehicle test results of a two axle coach, while the driver applies fully applied accelerator pedal and simultaneously steers the vehicle first in the clockwise direction, then in the counterclockwise direction, on wet polished cobblestone surface with μ = 0.2. The default parametrization was used for this case.

As can be observed from Figures 3a-c-e, as the rear wheel driven speed (blue curve in Figure 3e left axis) reach the initialization threshold (parametrizable red curve); i.e. as the rear tire slip reaches a certain threshold (can be observed by comparing the rear wheel speeds with the front ones in Figure 3c left axis, as well) at around t = 94.5 s, the ASR engine torque reduction is triggered, and the brake module starts controlling the engine torque. However, it is too late; shortly after this event, at around t = 95 s, the vehicle shows oversteering tendency while yawing clock-wise (yet the vehicle has just been

steered to the other side), and because of this tendency, ESP yaw control is activated; both engine torque is reduced and the front left brake pressure is demanded, as observed in Figure 3g.
Based on these observations explained above through the vehicle test results of Figure 3a-c-e-g, obtained during a steering maneuver on wet polished cobble-stone surface with $\mu = 0.2$, the idea now is reducing the ASR tire slip initialization thresholds such that engine torque reduction is applied earlier, such that yaw control activation is avoided. For this purpose, the initialization thresholds are lowered, and the result is shown in Figure 3b-d-f-h. As observed from Figure 3b-f, the driver applies the same steering maneuver, simultaneously flooring the accelerator pedal. However, as the ASR tire slip initialization thresholds are lowered now, the blue curve in Figure 3f reaches the now lower red curve earlier; at a lower amount of engine torque (please compare Figures 3a-b right axis, as well), therefore it takes over the control of the engine torque earlier compared to the default parametrization. The result is stabilizing the vehicle with ASR engine torque reduction solely, until t=111 s (Figure 3d right axis), without need of brake intervention through yaw control, as observed in Figure 3h (no ESP yaw control triggered).

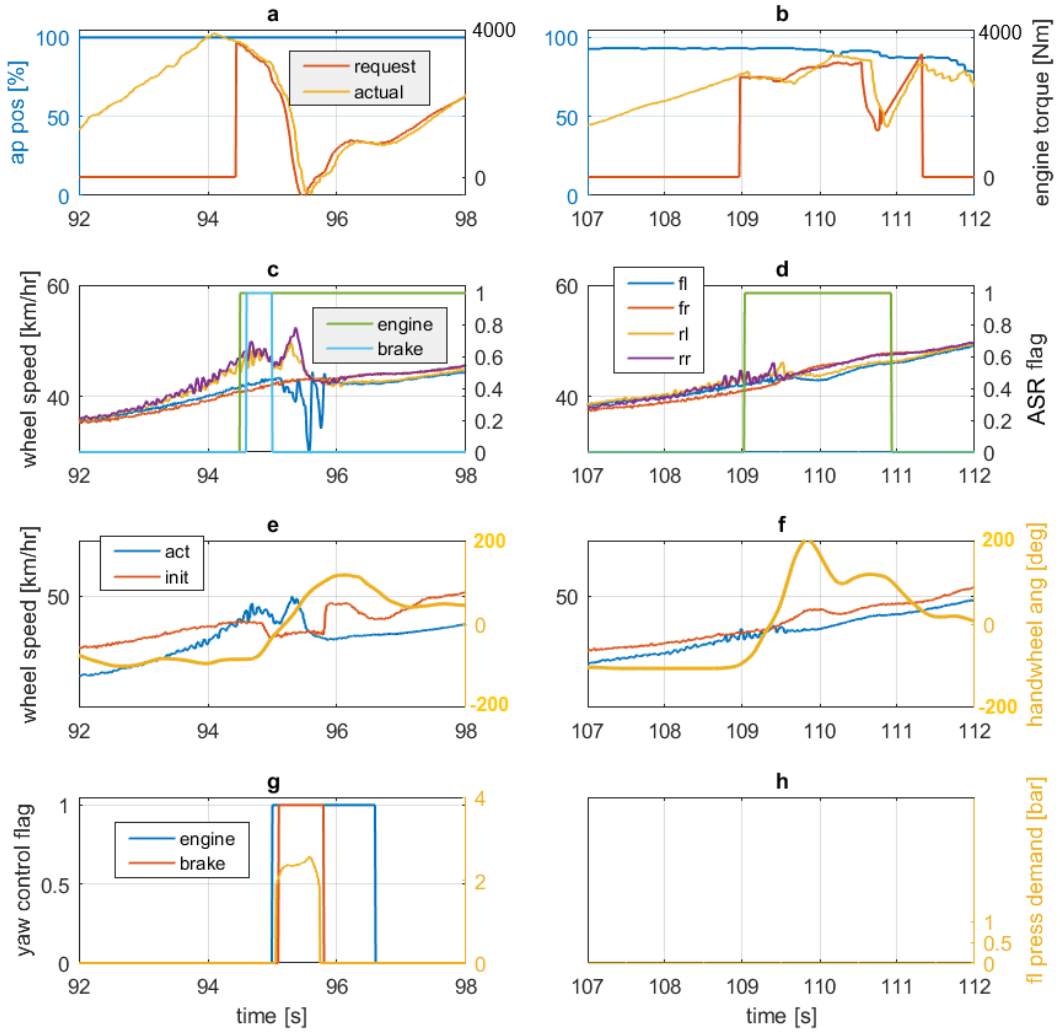


Figure 3. Top row: Left axis – accelerator pedal position, Right axis – engine torque; brake module requested engine torque, and the realized one by the engine, at the transmission output side. Second raw: Left axis – wheel speeds, right axis – ASR flags (engine torque reduction and brake intervention). Third row: Left axis – actual and initialization (parametrizable) wheel speed threshold. Right axis – handwheel angle. Fourth row: Left axis – ESP yaw control flags; engine torque reduction and brake intervention, Right axis – front left brake pressure demand by ESP yaw control algorithm.

4. TUNING THE GEAR DOWN-SHIFT MAPS DURING RETARDER LEVER BRAKING

Figure 4 shows a downhill braking event with the retarder lever, on asphalt, at an initial vehicle speed of around 90 km/hr, for the fully loaded three-axle coach. With the knowledge that engine brake operates more efficiently at higher engine speeds, the objective of the study was tuning the gear down-shift schedules during retarder lever braking. The tuning was performed such that the gear is shifted down earlier; at a higher rpm (highlighted in Figure 4f) compared to the default parametrization (Figure 4-e), as the vehicle slows down (Figure 4-a, b left axis). The tuned parametrization yields a more aggressive shifting pattern, ending up with a higher engine speed. The result in the efficiency of the engine brake is compared through Figures 4-c, d. The engine brake is utilized 27% more in total, with the tuned configuration (Figure 4-d) compared to the default parametrization (Figure 4-c) during the maneuver. It should be kept in mind that the loss of engine brake during down-shifts as observed in Figure 4c-d, is compensated by automatic service brake actuation, such that no unintended jerk, in deceleration trend is experienced.

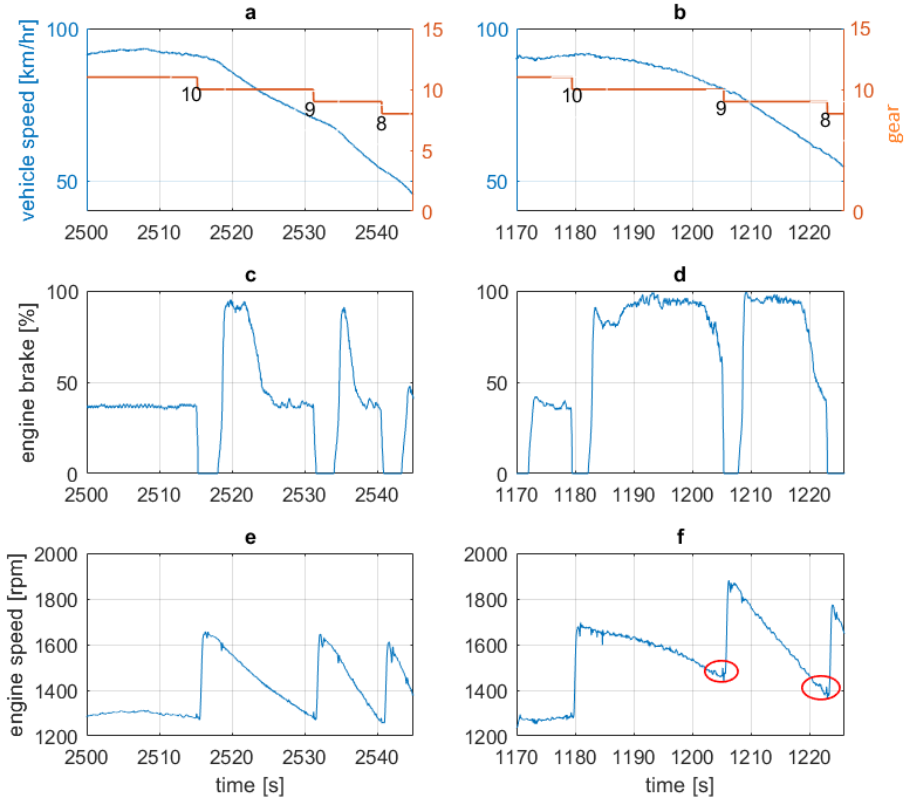


Figure 4. Retarder lever braking at an initial speed of 90 km/hr. Left figures a-c-e show the default parametrization, versus the right figures b-d-f show the tuned one, for getting more efficient engine brake.

5. CONCLUSIONS

This work summarizes tuning of three vehicle control features for diesel coaches. Before summarizing the results, it is important to note that vehicle tests for each three case, were performed multiple times. The results and therefore findings, were consistent with each other. Besides, tests were carried out considering both unloaded, and fully loaded vehicle conditions.

The first one is tuning the brake module ABS parameters of the three axle diesel coach such that during split μ braking, the level of counter steering towards the low μ side for holding the vehicle straight and the level of deceleration are balanced (without violating the limit given by Equation 1) in regard to ECE R13 regulation.

The second one is tuning the ASR tire slip initialization thresholds of the two axle diesel coach, such that during a steering maneuver on low μ, unnecessary ESP yaw control interventions are avoided.

The last one is tuning the gear down-shift schedule of the three-axle coach during retarder lever braking such that, the gears are shifted down earlier; at a higher engine speed. This yields utilizing the engine brake 40% more during the retarder braking maneuver.

Table 2 outlines the result of teach tuning effort, summarizing key tuning effort outcomes.

Table 2. Key tuning intervention / outcome of each tuning effort.

Case 1	Default parametrization	Tuning effort
Peak counter steering angle [degrees]	116	75
Mean ABS deceleration [m/s^2]	-3.13	-2.79
Case 2		
ASR tire slip initialization threshold [%]	10	4
Case 3		
Mean engine brake utilization [%]	37	64

As future work, the team will 1) analyze and study the autonomous steering controllers in literature for ABS braking on the split-μ surface and develop a new coordinated autonomous steering & ABS controller 2) apply the tuned ASR tire slip initialization thresholds to the vehicles, in winter test.

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