Effect Of Adaptive Cruise Control Usage To Brake Pad Life And Braking Feeling On Heavy Commercial Vehicle

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ABSTRACT: Adaptive cruise control (ACC) is an intelligent form of cruise control that allows vehicles to speed up and slow down automatically in order to keep pace with the traffic ahead. In cars, either a laser or radar system is mounted within the front of the car that constantly scans the road ahead of you for other vehicles. In recent years heavy truck drivers are likely to drive more autonomous vehicles. ACC is helping the driver to drive more safely and comfortable.

This paper presents effect of the adaptive cruise control (ACC) usage on brake pad wear of heavy commercial vehicle by comparing pressure and temperature differences seen on three different vehicle configurations. These configurations are "adaptive cruise control with engine brake & retarder & service brake", "adaptive cruise control with engine brake (without retarder) & service brake" and "engine brake (without ACC and without retarder) & service brake" at tractor vehicle. For all configurations same vehicle and trailer is used with configuring the software and hardware on the vehicle. The aim of this study is to compare the brake pad wear change by brake temperature and pressure differences with predefines test scenarios. Specific test procedure has been developed to get objective measurement and subjective feeling assessment on the vehicle. The test scenarios has been determined to profile the different adaptive cruise control usage scenarios as vehicle tracking and long haul drive.

The brake pad temperature, pressure and vehicle CAN data has been logged through of the test. Also driver perception has been rated for different adaptive cruise control, auxiliary brake system and service brake usage. The brake temperature and pressure data has been used to calculate the comparative brake pad wear change. It was seen that the adaptive cruise control usage with engine brake has positive effect on brake pad life as 2 % incremental to without ACC usage. Retarder usage has the longest pad life with ACC as expected with 23% improvement to without ACC usage. Thus adaptive cruise control usage effect to the pad life with same comparative test scenarios showed that adaptive cruise control has positive effect to the brake pad life.

KEY WORDS: Adaptive Cruise Control, Retarder, Pad wear, Heavy Commercial Vehicle, Auxiliary Brake

1. Introduction

Adaptive Cruise Control (ACC) system, evolved from the traditional Cruise Control (CC) system. Dang et al. (2015) proposed a coordinated ACC system that considered lane-change assistance. Apart from these research,

some researchers and manufacturers have considered driving styles to enhance user acceptance (Martinez et al., 2018). Embedding drivers' diverse characteristics into a traditional ACC system and making the controlled vehicle natural to human drivers are of vital importance to a comfortable and enjoyable driving experience.

As shown in Fig. 1, the longitudinal control process for an ACC-equipped vehicle can be divided into two segments according to the relative distance. When the relative distance between the two vehicles is higher, ACC operates in the speed control mode (also called CC mode), which acts as the Cruise Control system. The cruise speed set by a human driver is taken as the control target, and the host vehicle is kept at a constant speed. The distance control mode (also called ACC mode) is responsible for following the preceding vehicle at a safe distance. [1]

The purpose of this study is to compare the brake pad wear change by brake temperature and pressure differences with 3 different vehicle configurations.

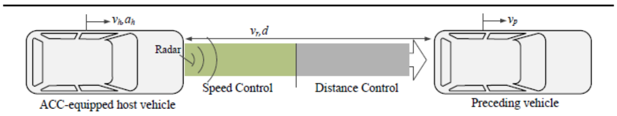

Fig.1. ACC control principle

2. Methodology

All vehicle configurations are equipped with engine brake. The aim of this study to understand is ACC better brake applicator rather than the driver while blending function on. Same driver used on all vehicle configurations and all road types.

Original Features of Vehicle:

- Transmission: ZF 12 TX 2620 AMT
- Engine: Ecotorq 500PS - 12,7L (Ford - Otosan design for Heavy Truck Commertial Trucks)
- Drive: 4x2

- Engine Brake: Jacobs – Compression Release Type 320kW
- Retarder: ZF Hydraulic Interder
- Service Brakes: Disc Brake

2.1. Vehicle Instrumentation

- Vehicle CAN log:

Brake temperature warning light
Brake chamber pressure
Pad wear percentage
ACC usage demand
ACC set speed
ACC mode
Retarder torque
Acceleration pedal position
Service brake pedal position
Auxiliary brake lever position
Blending usage
Transmission current gear
Engine speed
Vehicle speed
Engine brake boost pressure
Latitude
Longitude
Trailer weight
Vehicle following distance
Radar
Vehicle acceleration

- Embedded wireless thermocouple for all wheels (Figure 2)
- Pressure gage for all vehicles
- Datalogger

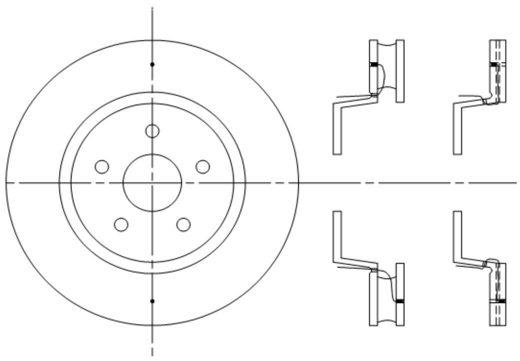

Figure 2 Embedded Thermocouple Installation

2.2. Vehicle Configurations

- Adaptive cruise control with engine brake & retarder & service brake
- Adaptive cruise control with engine brake (without retarder) & service brake
- Engine brake (without ACC and without retarder) & service brake

Vehicle configurations updated within same vehicle. Performed vehicle loaded to GTM [40 ton].

2.3. Test scenario

- Straight road to perform short brake applications (Bozüyük Köfteci Yusuf Road) – Figure 3
- Gradient road to perform %9 negative slope representation (Kütahya Road) – Figure 4
- Long distance performance (İnönü-Kocaeli road) – Figure 5

Each road type performed 2 times to increase sample size for each vehicle configuration. Test performed as showed Figure 6

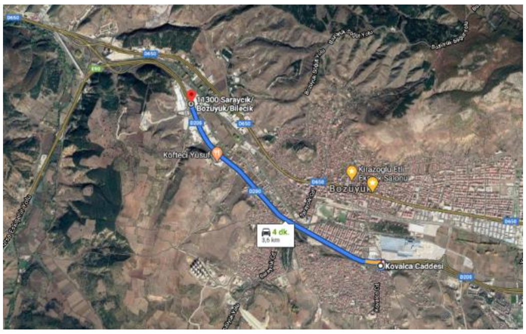

Figure 3 Bozüyük Köfteci Yusuf Road

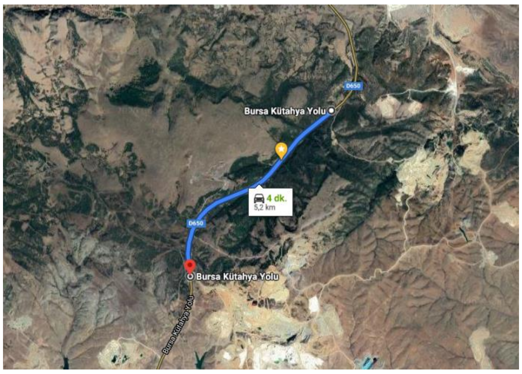

Figure 4 Kütahya Road

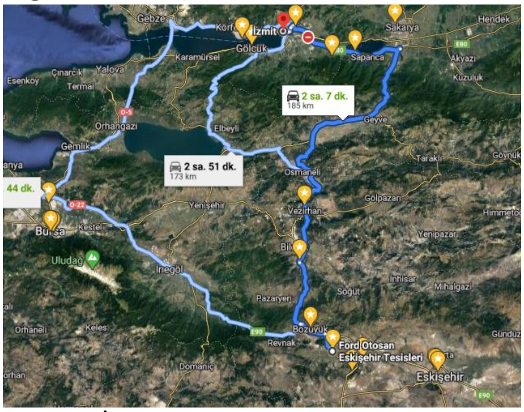

Figure 5 İnönü – Kocaeli Road

VEHICLE CONFIGURATION	TEST ROAD
ACC+Retarder+Engine Brake	Bozüyük Köfteci Yusuf Road (80 km/h to 40 km/h brake application x 3 times)
	Kütahya Road (Hill descent set speed-60 km/h) x 3 times
	İnönü-Kocaeli Long Distance Road (ACC brake application chosen short distance) x 2 times
ACC+Engine Brake	Bozüyük Köfteci Yusuf Road (80 km/h to 40 km/h brake application x 3 times)
	Kütahya Road (Hill descent set speed-60 km/h) x 3 times
	İnönü-Kocaeli Long Distance Road (ACC brake application chosen short distance) x 2 times
Engine Brake	Bozüyük Köfteci Yusuf Road (80 km/h to 40 km/h brake application x 3 times)
	Kütahya Road (Hill descent set speed-60 km/h) x 3 times
	İnönü-Kocaeli Long Distance Road (ACC brake application chosen short distance) x 2 times

Figure 6 Test Configuration

3. Results

3.1. Converging Evaluation

3.1.1. Köfteci Yusuf Road Data Analyze

Values shown in Figure 7.

- Brake pad temperature rise seen same between non-retarder vehicles. Vehicle with a retarder significantly lower pad temperature increase regarding to non-retarder vehicles.
- Only engine brake equipped vehicle brake chamber pressure is highest. ACC and retarder equipped vehicle has the lowest brake chamber pressure.

Köfteci Yusuf road analyse showed between only engine brake vehicle and ACC equipped only engine brake vehicles did not make major difference delta pad temperatures point of view. On the other hand ACC equipped only engine brake has better result the perspective of brake chamber pressure rather than only engine brake vehicle.

		AVERAGE VALUES (3 sample for each vehicles)		
		Delta Temperature [C]	Maximum Pressure [bar]	Deceleration [g]
Bozüyük Köfteci Yusuf Road	ACC + Retarder + Engine Brake	31,62	1,92	-0,13
	ACC + Engine Brake	50,61	3,77	-0,17
	Only Engine Brake	49,26	4,98	-0,24

Figure 7 Bozüyük Köfteci Yusuf Road Test Results

3.1.2. İnönü-Kocaeli Road Data Analyze

- ACC, retarder and engine brake equipped vehicle data analyse shown in Figure 8. Average brake pad temperature 49°C, peak temperature is 77°C.
  Average brake pad temperature will be 80°C, peak temperature will be 107°C if all vehicle type start conditions equalized.
- ACC equipped only engine brake vehicle data analyse shown in Figure 9. Average brake pad temperature 111°C, peak temperature is 175°C.
- Only engine brake vehicle data analyse shown in Figure 10. Average brake pad temperature 117°C, peak temperature is 286°C. Driver informed to behave same as ACC does to perspective of brake application distance. Driver preferably used engine brake at each brake application.

	T_1_L ?C
Min	31.73
Mean	49.43
Max	77.82

	P_1_R bar
Min	-0.031
Mean	0.012
Max	2.62

Figure 8 ACC, retarder and engine brake equipped vehicle result

	T_1_L ?C
Min	59.79
Mean	111.6
Max	175.7

	P_1_R bar
Min	-0.029
Mean	0.030
Max	3.57

Figure 9 ACC equipped only engine brake vehicle result

	T_1_L ?C
Min	52.42
Mean	117.8
Max	286.9

	P_1_R bar
Min	-0.039
Mean	0.027
Max	2.98

Figure 10 Only engine brake vehicle result

3.2. Academic Evaluation

The pad wear per unit energy absorbed can be considered only a function of contact pressure and temperature.

Wear Rate Calculation (pressure) Perspective:
In [2] Archard's law of wear is discussed which is given by;
$z = K \times pcontact \times vslide$
where:

- z is the wear rate
- wear K is the wear coefficient for which several models exist
- contact p is the contact pressure
- slide v is the sliding velocity

On order to Archard's law[2] ACC, retarder and engine brake equipped vehicle' pad wear is 46% lower than ACC equipped only engine brake vehicle'. On the other hand ACC equipped only engine brake vehicle's pad wear performance is better than only engine brake vehicle'. Calculated values shown in Figure 11.

		ACC Retarder Engine Brake Service Brake	ACC Engine Brake Service Brake	Engine Brake Service Brake
P_contact	-	NA	NA	NA
K_wear	-	NA	NA	NA
V_slide	average	64,01	59,60	56,91
Reservoir pressure	average	1,05	2,29	3,08
z	**average**	**67,99**	**136,98**	**191,67**

Figure 11 Wear rate calculation result

3.2.1 Wear Rate Calculation (energy) Perspective

Pad wear is dominantly depends on energy lost and temperature at which this energy is dissipated by pad material. Deceleration will not add extra thermal energy disc or pad. Data calculated per brake. Service brake need amount to perform same deceleration within each vehicle configuration calculated according to "wear rate calculation (energy)" which is in directly proportion to "Brake Energy". While rate rising, pad wear will increase. Only engine brake vehicle' service brake need calculated same as ACC equipped only engine brake to perspective of this calculation.

Calculation path shown in Figure 12. Calculation result shown in Figure 13.

$$Kinetic\ Energy = 0.5 * mass\ of\ vehicle * proportion\ ratio\ on\ axle * (v2^2 - v1^2)$$
$$E = 1/2 * m * v^2$$
$$Coast\ Down\ Energy = a + b * v + c * v^2$$
$$Brake\ Energy = Kinetic\ Energy - Coast\ Down\ Energy$$
$$Brake\ Energy = mass\ of\ Disc * Cp * Change\ in\ Disc\ Temp$$

Figure 12 Wear Rate calculation (energy)

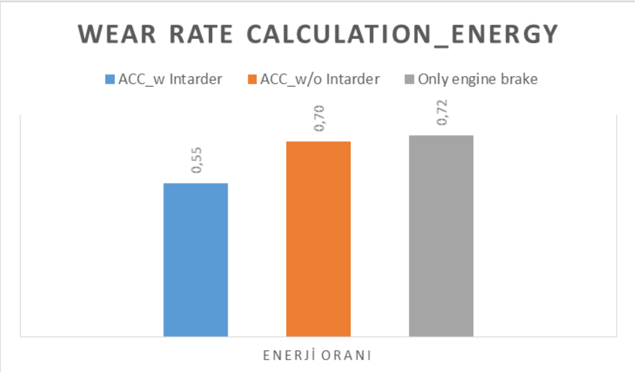

Figure 13 Wear Rate calculation (energy) results

3.2. Auxiliary Brake Performance Calculation Tool Results

Auxiliary Brake Performance Calculation Tool is inhouse tool that Ford Otosan uses to simulate auxiliary brake performance by taking into consideration transmission and engine capabilities. Tool result correction performance verified with various actual vehicle tests. Paper subjected test' calculation shown in Figure 14.

- Retarder and engine brake equipped vehicle is able to hold 30 kph while 10,5% negative slope road without needed service brakes.
- Only engine brake vehicle is able to hold 30 kph while 6,4% negative slope road without needed service brakes.

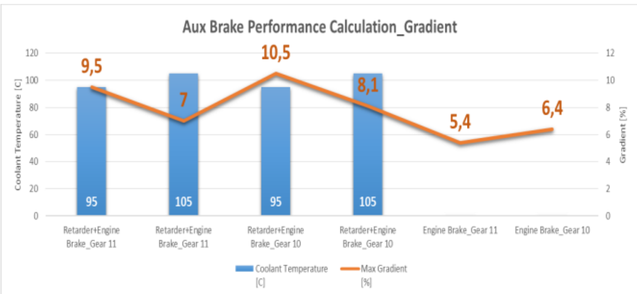

Figure 14 Wear Rate calculation (energy) results

4. Conclusion

The results can be concluded as follow:

- ACC equipped only engine brake vehicle' brake chamber pressure result is better than only engine brake equipped vehicle.
- ACC equipped only engine brake vehicle' average and peak brake pad temperature performance is significantly better than only engine brake equipped vehicle.
- According to Archard' law calculation result, ACC equipped only engine brake vehicle's pad wear performance is better than only engine brake vehicle'.
- Only "Pad wear (energy) calculation" shows only engine brake vehicle' service brake need calculated same as ACC equipped only engine brake.
- Auxiliary Brake Calculation Tool compares different equipped vehicle auxiliary brake performance's. Vehicle more weak without retarder.

As a result, ACC is better brake applicator rather than driver. ACC uses auxiliary brakes more optimized. Service brake pad life increased with optimized auxiliary brake usage.
Driver quote "I feel safer while ACC assistance".

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Thank you.