Heavy Commercial Trucks Auxiliary Brake Performance Metrics & Evaluation

[1]Ersen CERIT, Dilek BAYRAK AKCA, Y.Koray TASKIN, Yavuz AYDIN, Onur OZANSOY
[1]Ford Otosan Product Development Center, Kartal-Istanbul, Turkey

Abstract

Conventional service brakes have not been able to meet increasing demand on them due to several limitations, such as packaging limits, brake fading and excessive wear issues. As a result of these difficulties, vehicle manufacturers are introducing additional retardation mechanisms such us engine brake, exhaust brake, retarder or intarder. Their braking performance depends on several factors at system level and also at vehicle level.

Auxiliary brake system performance is initially measured on dynamometer to see its system power. However total auxiliary brake performance on the vehicle is affected by many factors such as tyre rolling resistance, air drag, engine compression, mechanical losses, and power consuming subsystems such as radiator fan. While engine speed is the main contributor for the engine braking power, driveshaft speed defines hydraulic retarders power. Another important factor for the intarder system is engine cooling water temperature. Cooling water temperature level is specified by many contributors such as radiator top off temperature, fan speed, engine speed, engine calibration, intarder calibration etc. The vehicle manufacturer calibration or algorithm definition creates their owned unique braking system performance.

Aim of this study is to define all of the critical vehicle level parameters and interactions on retardation performance first and than evaluate these critical parameters effects to see total vehicle retardation performance. While, ECE R13 Type IIA regulation test method is used to measure low vehicle speed retardation performance, high speed deceleration testing and sequencial engine loading via using towing dynamometer to simulate higher coolant temperature effect are found to be needed to cover full speed range and coolant temperature range in order to calculate total braking performance under all usage conditions.

Keywords: Auxiliary brakes, Secondary brakes, Intarder, Hydraulic retarder, Heavy duty vehicles, Vehicle testing

1. Introduction

Over the road trucks and tractor-semitrailer couples, engine brakes, exhaust brakes, hydraulic or electro-mechanical retarders are utilized with the main application being vehicle speed control while descending grades. Job specific vehicle applications, such as refuse collection trucks, will many times make use of a more efficient, higher capacity retarder devices. This study will focus on the auxiliary brake performance metrics and evaluation methods on the vehicle tests by using various retarder systems such as hydraulic retarder, engine brake and exhaust brake.

Retarder is defined as energy transformation device used to provide braking effort allowing control of vehicle speed independently of or as a supplement to the friction brakes. They are defined mainly two types as Primary and Secondary retarders according to ISO 611 (Ref-3). Primary retarder is located on the drive train of a motor vehicle at the engine side of the gearbox

*Corresponding author: Address: Ford Otosan Product Development Center, Kartal-Istanbul, Turkey

and Secondary retarder is located on the drive train of motor vehicles between the gearbox and the drive axle (Could be connected to non-driven axles as well).

Braking energy generated in the intarder system, hydraulic retarder coupled in transmission, is transfered into the thermal energy and hydraulic oil temperature is increased. Water/oil heat exchanger, used to reduce thermal energy of the intarder oil, could be integrated into the engine cooling system behind the radiator (cold water side) or engine (warm water side) (Ref-6). In this study warm side integrated intarder is used.

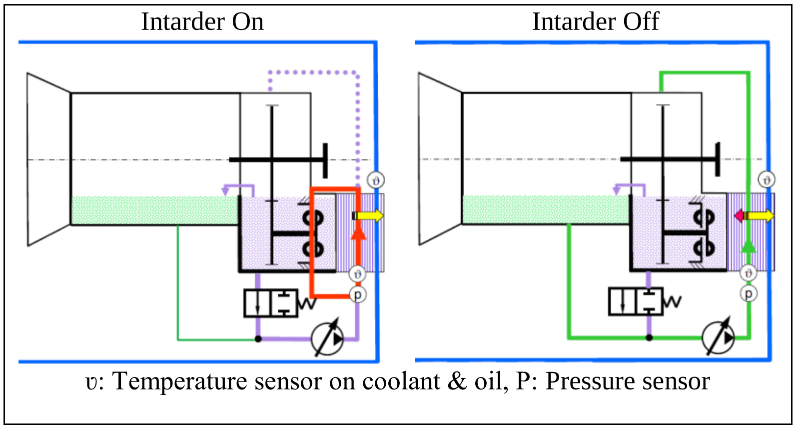

Figure-1. Intarder oil circulation diagrams (Ref-1)

For the used ZF intarder system, while intarder is off, oil is circulated in the transmission system for the lubrication, if intarder is activated; oil is circulated through stator-rotor couple and heat exchanger (Figure-1). During the retardation activity, engine coolant temperature, oil temperature and pressure are measured by sensors and thus oil pressure in intarder is adjusted by hydraulic pump as to the required braking power. On the other hand, if engine coolant temperature reaches to the defined value, based on engine cooling system performance oil pressure is reduced to limit braking power of intarder. Oil pressure and temperature define the braking torque on the rotor of intarder and so on the vehicle propshaft. Braking power is also related parameter with braking torque and propshaft speed (Ref-7).

According to ISO 611 standard; engine retarder mechanism in which an increased retarding effect is obtained by changing the valve timing to increase the internal resistance (drag) of the engine. Engine brake system opens the exhaust valves near the top of the compression stroke, releasing the highly compressed air through the exhaust system. Most of the energy is dissipated and thus vehicle slows down.

Table-1: Intarder braking power as to coolant temp.

Coolant Temp (^{o}C)	87	95	100	105
Max Available Braking Power (kW)	600	390	320	160

Figure-2 is showing dynamometer performance curves of engine brakes on different size engines. Braking power is increasing with engine size and engine speed, consequently braking power of all engine retarder systems mentioned above are directly related to volume and speed of the engine. On the other hand, performance of the intarder system is not related to engine speed, braking power is directly proportional to the propshaft speed, and related to oil temperature & pressure (See Table-1). As the performance of these mentioned braking systems are related to different vehicle parameters, it is clear to use different testing and evaluation methods for each system.

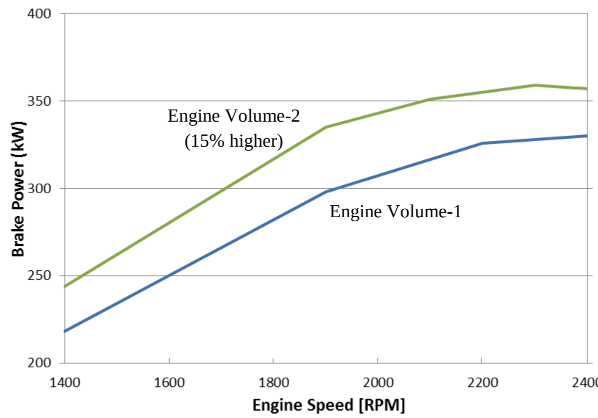

Figure-2. Engine brake power graphs with volume

ISO 12161 (Ref-4) specifies methods for testing the endurance braking systems of motor vehicles and towed vehicles. All endurance test procedures are based on the principle of equivalent energy absorption. The principle of equivalent energy allows the base test parameters to be adapted to the variations occurring under real conditions compared to theoretical values. Depending on the available test facilities the vehicles equipped with endurance braking systems shall be tested for type approval using one of the following types of tests: Downhill vehicle test, vehicle drag test and dynamometer vehicle test. All three tests are evaluated from downhill braking manoeuvres and are to different degrees gradient simulation tests.

According to the brake homologation requirement ECE R13 (Ref-5), testing method Type IIa defines the downhill track having 7% slope and 6km length. Or vehicle towing test could be used instead of the specific track. For vehicles in which the energy is absorbed by the braking action of the engine alone, performance of braking action of engine alone is determined by measuring the deceleration, it shall be sufficient if the mean deceleration measured is at least 0.6 m/s^2. A tolerance of ±5 km/h on average speed shall be permitted, and the gear enabling the speed to be stabilized at a value closest to 30 km/h on a 7 percent down-gradient shall be engaged. Deceleration test at high speed is also used for engine brake performance evaluation (Ref-8).

By this study, auxiliary brake systems and specifically engine brake and hydraulic retarders (intarder) are evaluated as to vehicle drag, deceleration and vehicle dynamometer tests. Next section is covering details for each testing method.

2. Testing and Data Evaluation

Testing methods mentioned above require data collection systems for objective evaluation. Some of the basic data such as vehicle, engine and radiator fan speeds are collected from the engine ECU directly, but the listed data below is collected by using measurement equipments and proper data collection system. Measured data are towing force, deceleration, Intarder coolant input /output temp & pressure, radiator coolant input & output temp, transmission oil temp, thermostat water temp, ambient temp and propshaft speed (See Figure-3&4).

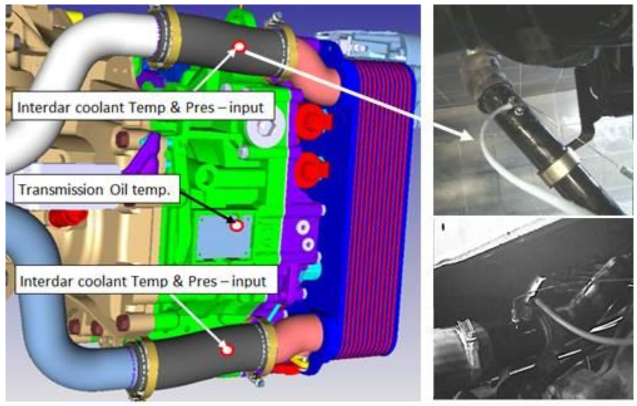

Figure-3: Instrumentation details of intarder.

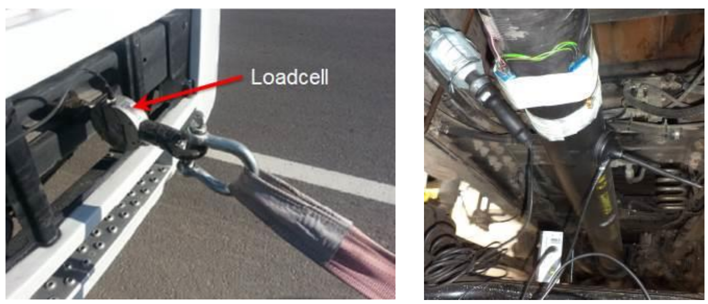

Figure-4: Towing load & Propshaft speed measurement.

SAE J1489 "Heavy Truck and Bus Retarder Downhill Performance Mapping Procedure" (Ref-2) provides a uniform method for calculating the vehicle Natural retardation power which include rolling resistance, aerodynamic drag, etc. The vehicle's inherent retarding power PN is a function of its speed, the road surface on which it is operated, its weight, properties of its tires, its frontal area, aerodynamic drag, ambient wind, and the altitude at which it is operated. Natural retardation power of test vehicles are calculated as 19.1 kW according to the formula and properties below.

Equ-1:

$$P_N(kW) = \frac{W(C_R + C_T)V}{367} + \frac{0.0024 C_d C_{AL} A V^3}{367}$$

$$C_{T:} (4.1 + 0.0026V) X10^{-3}$$

W: 32 ton, V: 30 km/h, A: 8 m2, Cd: 0.8, CR: 0.002, CAL: 1, CT: 0.005

2.1. Vehicle Drag Test

Vehicle drag tests are conducted to see performance of retardation systems for long continues usage simulating the hill descent at constant vehicle velocity. Test vehicle is the towed one and tries to keep the constant speed via braking. Vehicle speed is defined as 30 kph according to ECE R13 Type IIa regulation and this testing method is generally used to evaluate retardation performance at low vehicle speeds. While vehicle speed is kept constant and engine speed could be changed via gear shifting. Three different test vehicles with different wheelbase, engine, transmission, tyre were chosen for the comparative testing purposes. Vehicle 1 is a truck with engine brake alone, while vehicle-2 &3 are tractors both with engine brake and intarder.

Before calculating retardation systems pure performance, the vehicle losses have to be identified. Powertrain mechanical losses and engine power absorbing systems have also main contribution to the total losses on top of natural vehicle retardation power. Five different testing scenarios are defined to objectively gather the data not only for the total retardation power calculation but also for each losses coming from powertrain, engine compression, engine driven systems and vehicle natural retardation systems while vehicle speed is 30 kph and engine speeds are around 2300 rpm (Figure-5).

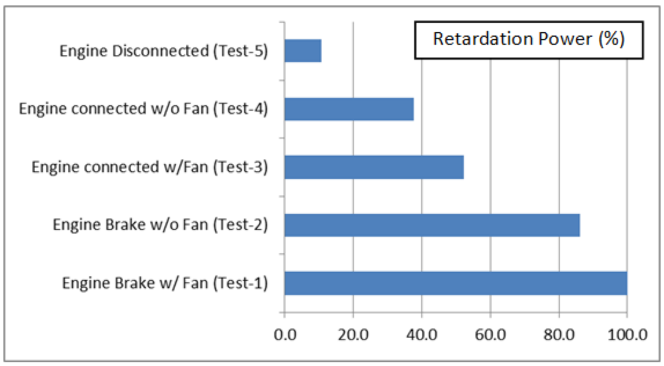

Figure-5: Retardation powers of veh-1 for five scenarios.

The first testing scenario (Test-1) is the total retardation power measurement with radiator fan fully engaged. Test-2 is to obtain the engine brake power without radiator fan while the same gear ratio is used. According to the first two testing results it can be concluded that the radiator fan can generate around 14% additional retardation power.

The third testing scenario (Test-3) is planned to get retardation effect of vehicle with engine connected and radiator fan active (52% power of test-1) while the fourth one is to calculate only vehicle losses while gear is engaged (38%). On the other hand, the last testing scenario is carried out to collect inherent retarding power of the vehicle (11%) while engine disconnected, calculated as 19 kW in Equ-1.

Table-2: Towing loads of drag test

	Towing Load (kg)	Shaft Speed (rpm)	Tyre
Vehicle-1	2300	475	295/80 R22.5
Vehicle-2	2100	450	315/80 R22.5

After the completion of the tests to measure losses coming from powertrain, engine compression, engine driven systems and vehicle natural retardation systems, intarder system performance measurement tests are conducted. This test was performed on the veh-2 & veh-3 already installed with the same intarder to see performance variation due to the parameters that are intarder coolant input /output temp & pressure, radiator coolant input & output temp, transmission oil temp, thermostat water temp, ambient temp and propshaft speed.

Vehicle drag tests are conducted this time with just intarder. The drag test results show that average towing loads are 2300 kg and 2100 kg for veh-2 & veh-3 respectively that are fairly low when compared to engine brake performance (Table-2). The reasoning is that intarder performance is not related to engine speed, but braking power is directly proportional to the propshaft speed and transmission oil temperature & pressure and engine system cooling system capacity. During the vehicle drag testing the propshaft speed is around 450 rpm (see Table-2). As the intarder braking torque is proportional to the shaft speed (Ref-7), these results are expected.

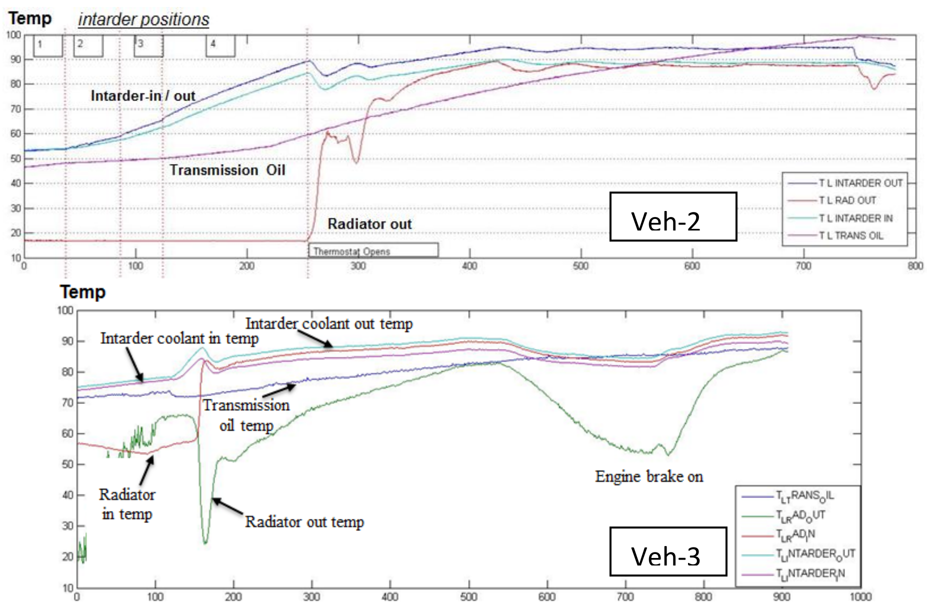

Figure-6: Coolant temperatures of Vehicle-2 & Vehicle-3

Figure-6 is showing the intarder coolant in/out, radiator in/out and transmission oil temperatures variation during vehicle drag testing. Both vehicles' intarder coolant outlet temperatures are similar, around 90 ^{o}C fairly below 100 degrees around which intarder system performance start to decrease. According to the Figure-6, we could observe that when radiator inlet temp reaches around 85 ^{o}C, thermostat opens and coolant water is circulated in radiator to cool down the engine coolant temperature. This strategy is important to maintain high intarder performance while continues braking is needed for long hill descents.

Since the vehicle drag test is not possible to be performed at higher vehicle speeds such as between 60kph and 80kph due to the maximum capability limit of tow dynamometer, vehicle deceleration testing is required to see intarder performance variation at higher shaft speeds where intarder performance reaches maximum retardation power.

2.2. Vehicle Deceleration Test

Deceleration tests are conducted to see vehicle overall retardation performance at high vehicle speeds including mechanical losses of the vehicle. The first test trial was performed on veh-2 via using max intarder stage while engine connected and at full vehicle load on a flat road.

Intarder deceleration tests are performed at max high speed acceptable for onroad conditions, which is 80 kph, to reach high shaft speeds. Deceleration tests are sequentially carry out around 80 to 60 kph when engine connected. At first trial and at max intarder lever position, retardation power reachs to maximum levels. It should be considered that natural retardation of the Veh-2 at this speed is around the 90 kW, calculated by using Equ-1. Intarder retardation powers in first three applications, listed in Figure-7, are around 600 kW except vehicle losses. The retardation power values are fairly higher than the results of vehicle drag test in Section 2.1 as expected. Main reason of power difference is the higher shaft speed, around 1300 rpm, when vehicle speed between 60-80 kph.

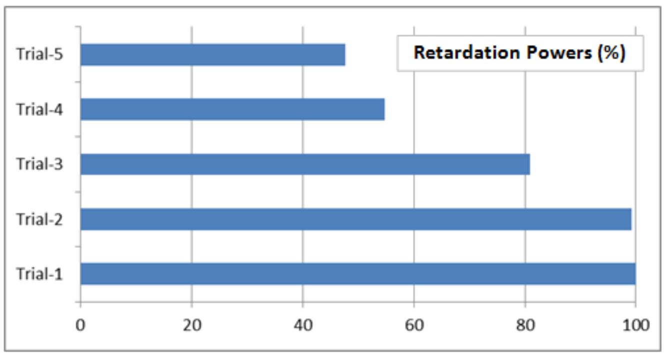

Figure-7: Intarder deceleration test results

Moreover, the above mentioned retardation powers are not the same and even reducing continouesly after a few application. To understand the reason behind, intarder coolant outlet temperature should be checked as in Figure-8. The coolant temperature is increasing after each brake application and passes 90 ^{o}C before the fifth braking. Therefore intarder power drops to 50% of cold condition at the last brake application (See Figure-7).

Engine brake deceleration tests are conducted at 30 kph between the engine speeds 2100-1500 rpm to quantify the difference from the vehicle drag test. The retardation powers are measured around 350 kW for each test on the Veh-2. These results are consistent with the measurements of Veh-1 at Section 2.1 and proving that the vehicle drag test is fairly enough to define the total retardation power of engine brake or similar systems.

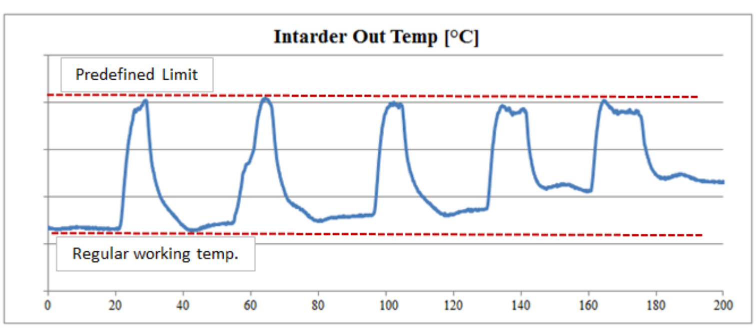

Figure-8: Intarder coolant outlet temperature vs time

The vehicle manufacturer calibration or algorithm definition creates their owned unique braking system performance. For example, fan activation is initiated depending on engine brake / intarder system on/off status or fan speed is defined acc to the engine coolant temperature level. Moreover, the fan speed is gradually increased to keep the engine coolant temperature below the predefined limit such as 100 ^{o}C depending on vehicle retardation system need.

There are different activation conditions for the radiator fan. Depending on the engine brake calibration strategy, if engine brake is active, fan can be activated at predefined speed such as 1000 rpm to increase retardation power on engine. If intarder is activated, fan is full engaged, such as 1400 rpm reduce coolant temperature. Otherwise fan is working depending on engine coolant temperature such that when temperature reachs to around 100 ^{o}C, fan is activated by engine ECU gradually to keep this temperature.

Although coolant temperature reduces abruptly when radiator fan is fully activated, performance of the intarder can reduce after a few brake applications as indicated in Figure-7. The continoues braking application, such as long hill descent, could not be simulated by deceleration test due to the vehicle speed drop by high intarder power on a smooth road. The hill descent after long climbing on uphill road condition is critical to replicate, because coolant temperature is already high at the start of braking and enables to measure intarder power with higher coolant temperatures. To simulate this condition vehicle dynamometer tests are needed and performed in addition to drag & deceleration tests.

2.3. Vehicle Dynamometer Test

Vehicle dynamometer tests are performed at climatic room to arrange ambient conditions and engine is fully loaded to heat coolant water at the beginning of the test. Vehicle’s live axle wheelends are connected to the dynamometer flanges to record braking power. Dyno tests were performed on the test veh-2 (See Figure-9).

Dyno tests are conducted at two different shaft speeds to see intarder performance variation. First testing case is 500 rpm shaft speed, simulating the vehicle velocity around 30 kph and second case is the 1000 rpm for 60 kph vehicle speed. At the beginning of both testing, engine coolant is heated up to reach worst case coolant condition for the intarder usage.

Figure-9: Vehicle dynamometer test

Table-3: Low & High speed testing results

	30 kph / 500 rpm		*60 kph / 1000 rpm*	
	Start	**Finish**	**Start**	**Finish**
Shaft Speed [rpm]	500		1000	
Engine Speed [rpm]	1100		1300	
Fan Speed [rpm]	1400		1700	
Intarder In/Out Diff Temp. [°C]	+9	+11	+9	+13
Trans. Oil Temp. [°C] increase	+12		+13	
Power Lost/Gain @Cont. Braking	3 kW loss		68 kW Gain	

While the first test condition, shaft speed is low and consequently intarder braking power is 26% of maximum power measured by vehicle drag test in Section 2.1. After the three minutes of intarder usage period, the coolant water temperatures at inlet and outlet ports of the intarder are reduced almost 2°C and thus only 3 kW power lost is observed (See Table-3 & Figure-10).

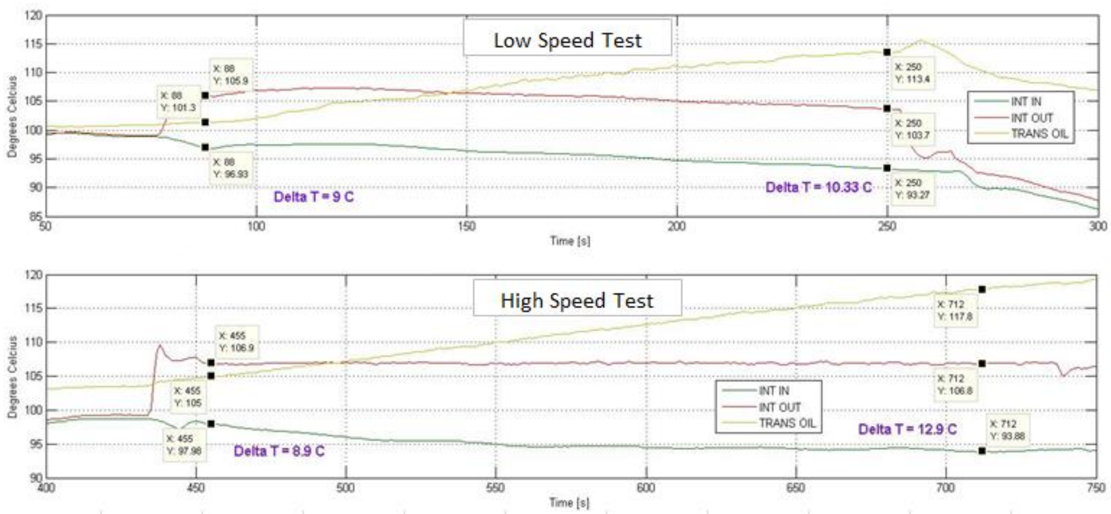

Figure-10: Low & High speed testing -Temperature graphs.

At the beginning of the second testing condition, called as high speed, 27% intarder braking power is obtained. After the two minutes braking period, power increased up to 37% and during the next two minutes it was almost constant. Temperature of the coolant water at intarder inlet port, in Figure-10 shows similar behavior like braking power. Temperature reduce 4 °C in two minutes and stays almost constant until the test end. During the test, intarder outlet temperature is almost same and transmission oil temperature increase 12 °C (See Table-3 & Figure-10).

By using dynamometer test method, worst case usage conditions, high coolant temperature, long retardation usage are simulated for intarder brake system, and at the end of the high speed test, 37% retardation power of cold condition is reached. If the results of deceleration tests in Figure-7 are considered, it has seen that minimum performance is 48% at the end of fifth application when temperature of intarder coolant outlet is lower than 100 °C. Coolant temperature at intarder out is almost constant and around 107 °C during the high speed dynamometer test (See Figure-10), thus lower retardation power 27% is measured as expected.

Conclusions

In this study, performance test evaluation methods of auxiliary brake systems on HCV are developed. Vehicle drag test is used to measure engine brake and also intarder performance at low shaft speed. The results are proving that drag test is suitable for performance evaluation of the engine brake or other primary retarder systems, however it is not sufficient for the testing of secondary retarder systems such as intarder due to low shaft speed and lower coolant temperatures. During the vehicle drag testing inherent retardation of heavy commercial trucks are measured and correlated with the natural retardation power calculations.

Since the vehicle drag testing is not adequate to cover all performance curves of intarder system except low shaft speeds, vehicle deceleration test at higher shaft speeds is required to be identified to measure maximum intarder or secondary retarder systems power at low engine coolant temperatures On the other hand, the vehicle deceleration test method provides the same results with the drag test for the engine brake performance. Thus, both methods could be used for primary retarder systems.

Although the maximum intarder braking power could be obtained with deceleration test, the effect of engine coolant temperature on the intarder performance can not be observed. Therefore, dynamometer test need is apparent to replicate worst case working conditions, high coolant temperature and long retardation usage for secondary brake system. The lowest intarder performance can be simulated via the vehicle dynamometer testing as well.

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