

Vehicle Demonstration of 2 Stroke Engine Brake in a Heavy Duty Truck

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ABSTRACT

Heavy duty valvetrains have evolved over the last 20 years with the integration of engine braking into the valvetrain. Jacobs Vehicle Systems have developed the High Power Density (HPD) engine brake that increases retarding power, especially at low engine speed. The system works by converting the engine from a 4 stroke during positive power into a 2 stroke for retarding power. This more than doubles the retarding power at cruise engine speeds reducing the need to downshift in order to control the vehicle, compensates for reduction in natural vehicle retarding due to aerodynamic and friction enhancements, and enables the same vehicle retarding power with a smaller displacement engine as engine downsizing becomes prevalent. This paper describes lessons learnt during a recent vehicle demonstration project undertaken by Jacobs including performance, durability, integration with the engine powertrain, controls development, calibration, management of air system and transient operation.

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INTRODUCTION

Compression-release engine braking or "Jake Braking" is used to slow heavy machines, such as, heavy duty trucks and construction/agricultural equipment [1]. In many markets around the world the engine brake has become standard equipment due to its ability to provide fade free stopping ability while reducing the wear on wheel brakes. The compression release engine brake works in concert with the engine's positive power valvetrain to effectively convert a diesel engine from a power producing machine into a power consuming air compressor through selective control of various engine valves.

Several fuel efficiency trends are driving improvements to retarding performance, particularly at low engine speeds:

- Reduced aerodynamic drag and rolling resistance reduce a trucks natural retarding
- Engine downsizing reduces the total retarding power compared to the larger displacement engines
- Downsizing promotes operation at low engine speeds to reduce engine friction resulting in low retarding power without a downshift
- Mass reduction increases the penalty associated with driveline retarders due to their mass and cooling pack requirement
- Legislation allowing higher truck GVW is being promoted in many areas
- Reduced freight delivery times required to maintain fleet competitiveness increase the desire for higher downhill speeds
- Thermal management of the aftertreatment system during descents to maintain NOx conversion efficiency

As a consequence, there is a need for increased engine retarding performance, particularly at low engine speed.

MARKET AND VEHICLE SELECTION

European fleets often specify driveline retarders suggesting an appreciation of the value offered by high vehicle retarding power. Driveline retarders function by converting the kinetic energy of the vehicle to heat via a hydraulic turbine connected to the driveline. The heat generated in the hydraulic fluid is dissipated in the engine cooling system.

While driveline retarders provide increased retarding performance over standard compression release brakes, they are an expensive option which add considerable mass to the vehicle and can exceed the thermal capacity of the radiator during prolonged retarding [2].



Figure 1. 2 stroke demonstration vehicle

2 stroke engine braking provides increased retarding power compared to a standard CR brake across the engine speed range at virtually no mass penalty, no increase in heat input into the cooling system over standard CR brake and considerably lower cost and system complexity than driveline retarders.

JVS selected a Mercedes Actros, 1845 LSN, 4X2 specification in Europe as a base vehicle (Figure 1, Table 1) to demonstrate 2 stroke brake technology. This enabled a comparison to production hardware which JVS already provides in a truck with CR brake and driveline retarder options in an integrated platform. This was performed without the assistance of Daimler in order to allow JVS to publicize the test data and obtain voice of the customer feedback from multiple stake-holders.

Table 1. Specification of demonstration vehicle

Vehicle	Mercedes Actros, 1845 LSN, 4X2
GVW	18t
GCW	42t
Axle ratio	2,611 :1
Tyre size	BRIDGESTONE 315/70 R 22,5
Engine	OM471, 12,8l, 6 cyl in-line
Power	339 kW @ 1800 rpm
Torque	2400 N.m. @ 1100 rpm
Transmission	Powershift 3 AMT 12-spd
Ratio spread	14.93 – 1.0:1

COMPRESSION RELEASE ENGINE BRAKE

Compression release engine brake or Jake Brake® is a device commonly found in vehicles operating over 30 tons. Engine brakes provide supplemental braking force on heavy vehicles reducing the thermal loading on the vehicle's service brakes. Typical diesel compression release engine brakes operate by actuating one or more exhaust valves near piston top dead center (TDC) on the compression stroke. As the piston approaches TDC of the compression stroke, the exhaust valve is opened, exhausting the high pressure air in the combustion chamber (Figure 2). The release of compressed gases into the exhaust manifold prevents the energy stored in the compressed gas to return to the piston on the subsequent expansion stroke. This net loss of energy is called 'engine retarding' and decelerates the vehicle.

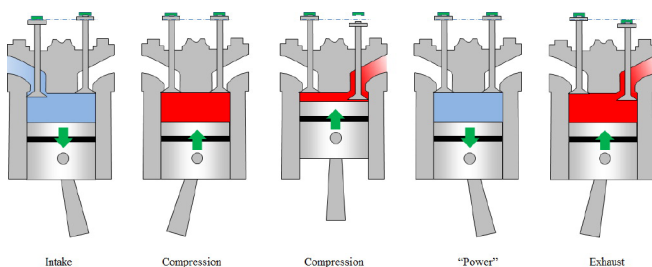


Figure 2. Typical engine cycle during compression release braking

The valve motions for 4 stroke engine braking are shown in Figure 3 with the compression release exhaust valve lift at 0deg TDC with the Brake Gas Recirculation valve event at bottom dead center to enable increased charge into the cylinder from the exhaust manifold as the intake valve closes.

The thermodynamics of engine braking for standard 4 stroke and 2 stroke braking is described by Fuchs et al [2].

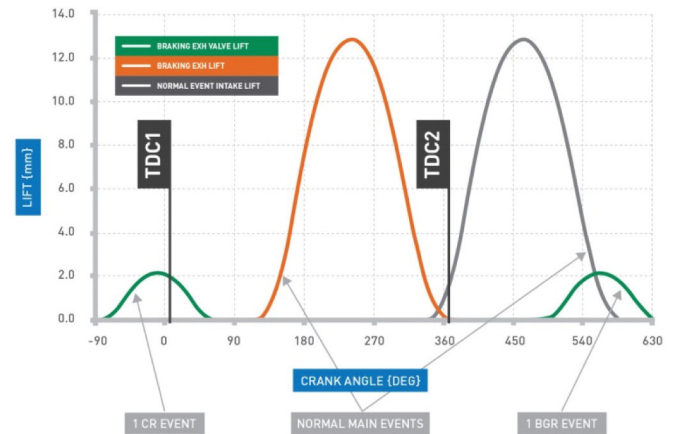


Figure 3. 4 stroke compression release valve lift

2 STROKE COMPRESSION RELEASE BRAKE

A standard compression release brake, such as many in production today, follow the 4 stroke engine cycle with a single compression release event occurring after the compression stroke resulting in 1 event for every 2 revolutions of the crankshaft (see Figure 3).

A 2 stroke compression release brake has a compression release event at every TDC event. This is enabled by disabling the main intake and exhaust valve events and actuating the valves in order to achieve an engine braking event every revolution of the crankshaft (see Figure 4). As a consequence, there are twice as many valve events that occur in 2 stroke braking as with a 4 stroke brake. This results in increased retarding power, particularly at low engine speed where the engines operate during vehicle cruising.

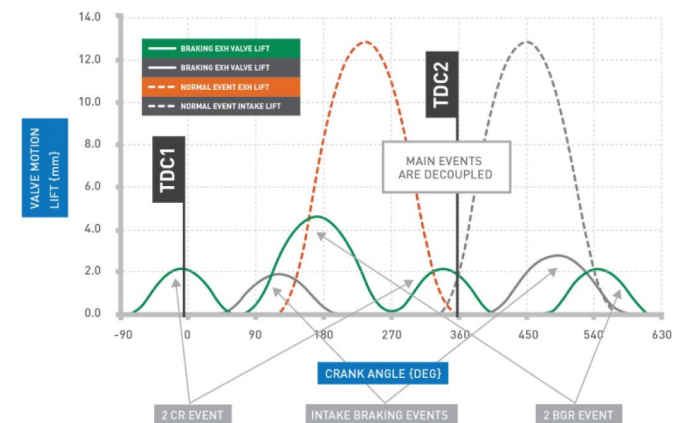


Figure 4. 2 stroke compression release valve lift with brake on

A key aspect of developing effective retarding performance is the interaction between the engine valve motions and the engine boost system. The level of boost that is achievable has a very strong influence on the available retarding power due to the increased trapped mass in the cylinder that is compressed resulting in increased pressure during the compression event.

The turbocharger is typically optimized around the positive power cruise condition which results in a turbine that requires significantly more enthalpy than is available during engine braking as there is no heat input from combustion during retarding. This results in the turbocharger operating in an area of the turbocharger map during engine retarding which generates low levels of boost at low engine speed.

With 2 stroke engine brake engine operation, the mass flow is much higher than standard compression release operation resulting in the compressor operating with increased boost and mass flow at low engine speed compared to a 4 stroke CR brake resulting in a significant increase in engine retarding power at low engine speed (Figure 5).

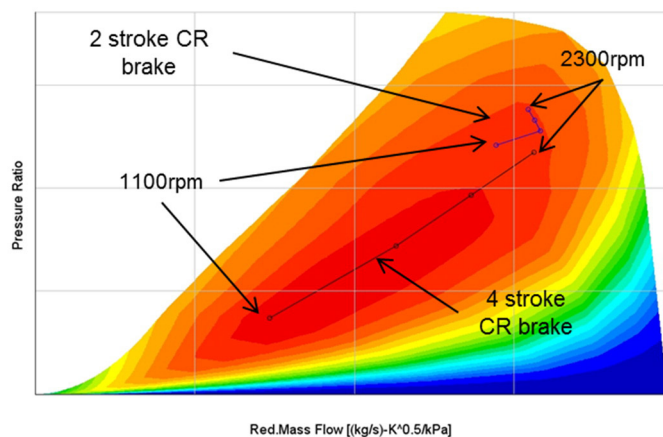


Figure 5. Compressor Map comparing operating points for 4 stroke and 2 stroke CR brake

With the increase in engine retarding power at low engine speeds, there is reduced requirement to downshift in order to achieve the desired retarding performance which reduces fuel usage used to accelerate the engine during the downshift to match the shaft speeds, improves driver comfort due to lower engine operation and reduces the potential for engine overspeed through selection of inappropriate ratio.

CONTROLS STRATEGY BENCHMARKING

In order to understand the requirements for the HPD engine brake, JVS performed benchmark studies on a Freightliner Cascadia in USA and a Mercedes Actros in UK. The Freightliner was more readily available providing early information on how the vehicle used the engine brake. For example, Figure 6 shows the use of the engine brake during upshift events requested by the AMT. By applying the engine brake after the transmission has declutched, the engine speed will decrease to the target engagement speed in a shorter period of time enabling faster upshift events. The engine brake solenoid signal is employed before the last fueling event, but prior to the engine brake valve motions due to the delay from the hydraulic system

associated with the engine brake actuation. The front engine brake solenoid activates the front 3 cylinders for AMT upshift events. This necessitated a method of applying the engine brake rapidly without any risk of fueling with the cylinder deactivated when the truck has completed the shift event.

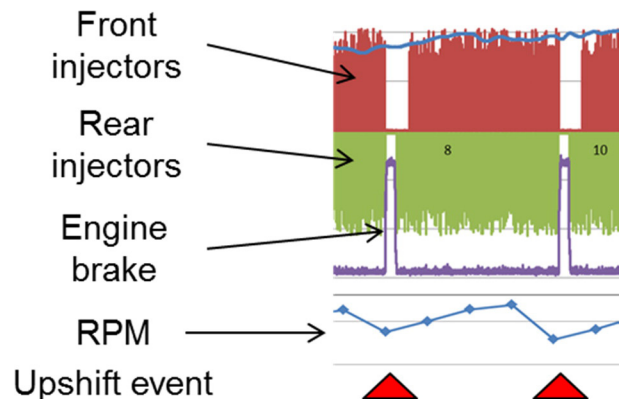


Figure 6. Engine brake use during transmission upshift

For high and medium braking operation, the engine brake was activated on 6 cylinders (front and rear solenoids). The difference between high and medium braking is the boost level based on the EGR valve position. As the EGR valve position is controlled by Daimler's proprietary CAN protocol, an alternative approach for boost control was required.

For low braking, the engine brake activation was found to differ between the Freightliner and HPD vehicle that was purchased. The Freightliner applied the front engine brake to achieve low braking, while the Actros provided low engine braking with the rear 3 cylinders via the rear solenoid. As a consequence, the controls strategy required the ability to control either front or rear solenoid independently during braking.

SYSTEM REQUIREMENTS

To account for critical operating modes observed in the vehicle, the hydraulic system was required to have the following operating modes feasible:

1. 2 stroke engine braking mode on 6 cylinders
2. 2 stroke engine braking mode on front 3 cylinders
3. 2 stroke engine braking mode on rear 3 cylinders
4. Engine braking with no valve deactivation on front 3 cylinders (for upshift)

The following requirements were placed on the brake control strategy from benchmarking the vehicle:

1. Activate engine brake in 6 cylinder operation and control boost pressure to achieve high and medium braking. This was later revised to provide infinite control between high and medium braking levels using a dash mounted potentiometer
2. Activate engine brake in 3 cylinder operation (front or rear) and control boost to target boost level