

Development of a High Performance Two-Cycle Engine Brake for Medium and Heavy Duty Diesel Engines

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ABSTRACT

Jacobs Vehicle Systems has been leading the development of engine braking technology for more than 50 years. In order to meet the need for significantly increased vehicle retarding capability, the company focused on the development of a High Power Density (HPD) braking system.

Overall vehicle retarding requirements are continuously increasing due to vehicle changes that improve fuel economy, such as increases in aerodynamic efficiency and decreases in rolling resistance, which in turn, reduce the vehicle's natural retarding. This increase in overall vehicle retarding needs comes at a time when the trend is to operate at lower engine RPM's combined with downsizing of engine displacement to improve fuel economy and reduce CO₂ emissions. The smaller displacement engine will clearly produce less retarding power than the larger engine it is replacing with standard engine braking technology.

In anticipation of this challenge, Jacobs Vehicle Systems has developed an engine-integrated solution that will deliver large-engine braking power in small and medium size engines, as well as reduce the overall loading on the valve train during braking.

The Jacobs' HPD brake provides for two-stroke engine braking on a four-stroke diesel engine. This maximizes braking performance, which results in an average increase of 104% in braking performance over a conventional compression-release engine brake, particularly at lower engine speeds where more than 200% gain in braking performance was measured. By distributing the braking effort over two events during the engine's full four-cycle process, the valve train loads generated during braking are reduced by as much as 30%.

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INTRODUCTION

A compression-release engine brake or retarder is used as an auxiliary braking device to slow a vehicle such as a heavy duty (HD) diesel commercial vehicle. Current engine brakes, such as the Jake Brake® engine retarder use the four-stroke cycle similar to positive power. This generates one braking event per four engine strokes or two crank revolutions. Four stroke compression-release braking operation is well known. [Figure 1](#) demonstrates the four stroke engine operation with compression-release activated during the compression/expansion part of the cycle when the engine is not fueling.

The wasted "POWER" and exhaust events are converted into an additional intake, compression, and compression release events.

[Figure 2](#) shows the Pressure-Volume diagram and braking valve lift (BVL) combined with normal exhaust and intake valve lifts for a typical four stroke braking cycle. As the engine piston approaches top dead center *compression* (TDCC), at

least one exhaust valve per cylinder is opened to release the compressed gases to the exhaust manifold, thus preventing the energy stored in the compressed gasses from being returned to the piston on the subsequent expansion down stroke. In doing so the engine is temporarily turned into an air compressor and develops retarding power to slow the vehicle. As shown in the P-V diagram, the engine braking performance is determined by the sum of the compression work (compression-release loop), the gas exchange pumping work (pumping loop), and mechanical friction losses.

The classic Jake Brake retarder was developed based on Clessie L. Cummins' invention¹ and first commercially introduced in 1961. It has undergone many development changes throughout the years to meet customer demands and the ever-increasing retarding power needs for more aerodynamic vehicles, with higher tare and gross weights.

Earlier engine brake systems were designed to open both of the exhaust valves on four-valves-per-cylinder engines.

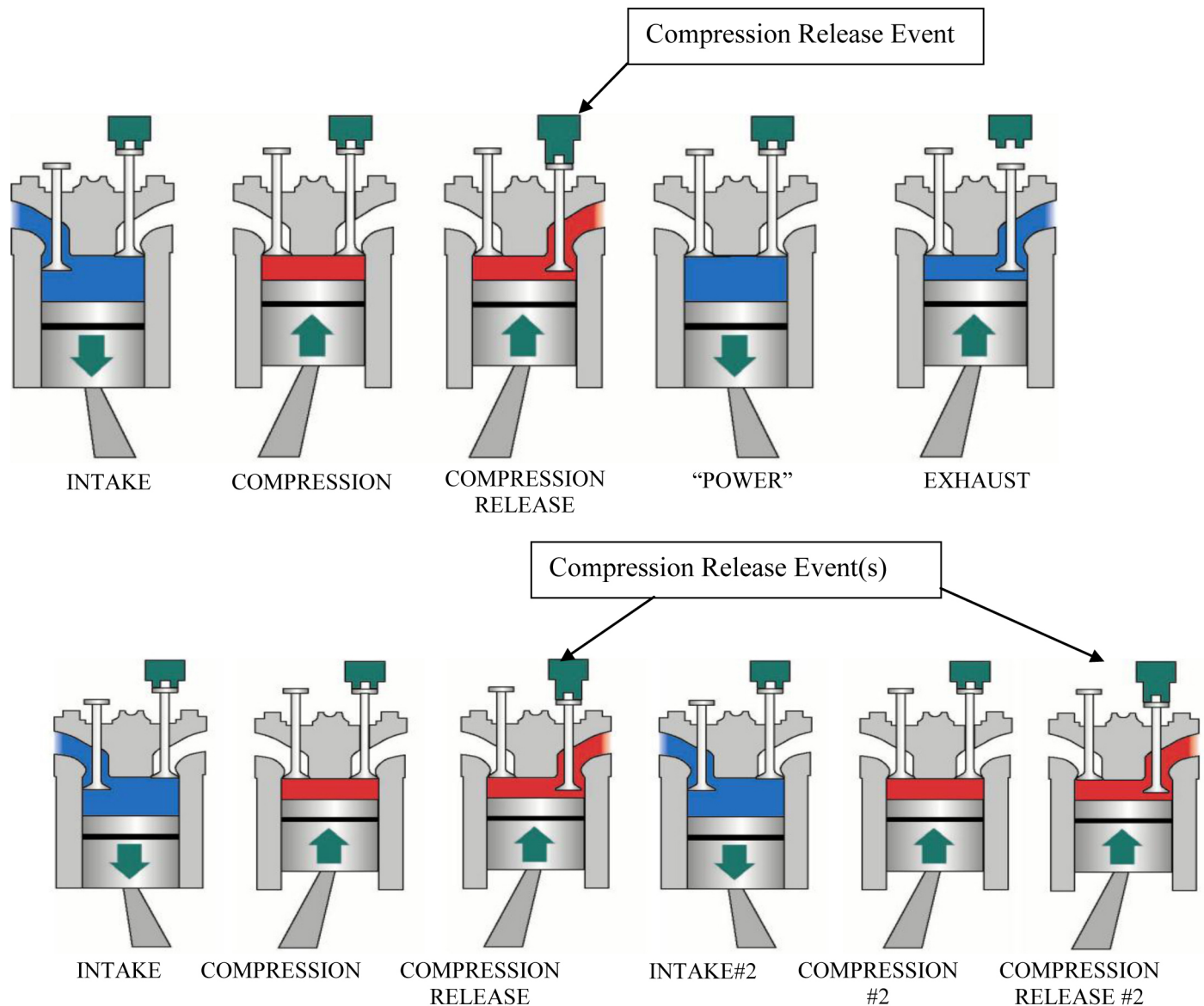


Figure 1. Compression-release Retarding comparison of 4-cycle vs. 2-cycle (HPD)

The retarding power, as well as the braking loads on valve train components, increased as turbocharger performance increased. Later it was found that by opening only one exhaust valve, the braking load would be greatly reduced, thus, the retarding power limits have increased over time. As shown in [figure 3](#), since 1961, with the addition of the HPD brake, the available retarding power at 1500 RPM has increased by 18 kW/L.

In the late 1990's Jacobs, in joint cooperation with the customer, introduced the Intebrate™ for the Signature 600® Cummins engine that utilizes a Dedicated Rocker Brake (DRB). This brake uses a dedicated brake cam lobe as well as a Brake Gas Recirculation (BGR) cam lobe. The BGR valve opening is used to introduce exhaust manifold gas into the cylinder to increase the mass charge, thus increasing the work the engine has to do in compression. The DRB is capable of

achieving comparable retarding power as the engine's positive, (447KW).

The braking power has continued to increase over the years, but physical limitations of the engine have been reached relative to push tube loads, cam Hertz stresses, or overhead loading capacity limitations. With the advent of common rail fuel systems, engine designers have optimized the head for reduced positive power loading. The head no longer needs to carry the high loading from direct injection through the valve train, thereby limiting the load carrying capability available for the braking system.

Two-Stroke Braking

Two-stroke compression braking releases stored energy each time the piston reaches Top Dead Center (TDC). The two-stroke braking idea has been around since 1927^{10, 32}

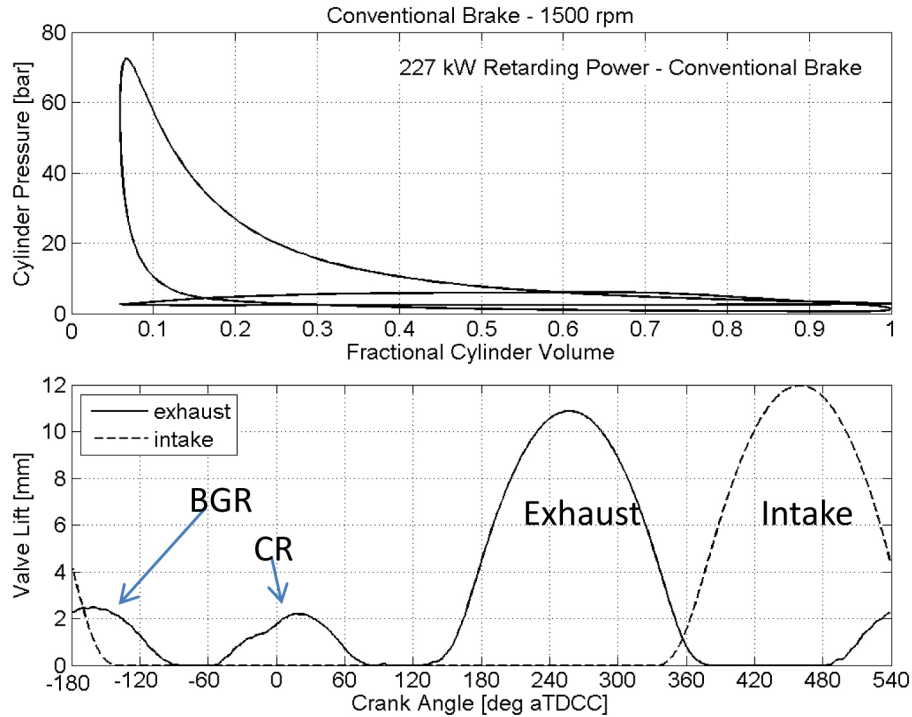


Figure 2. PV Diagram and Valve Opening Events- 4-Stroke Braking

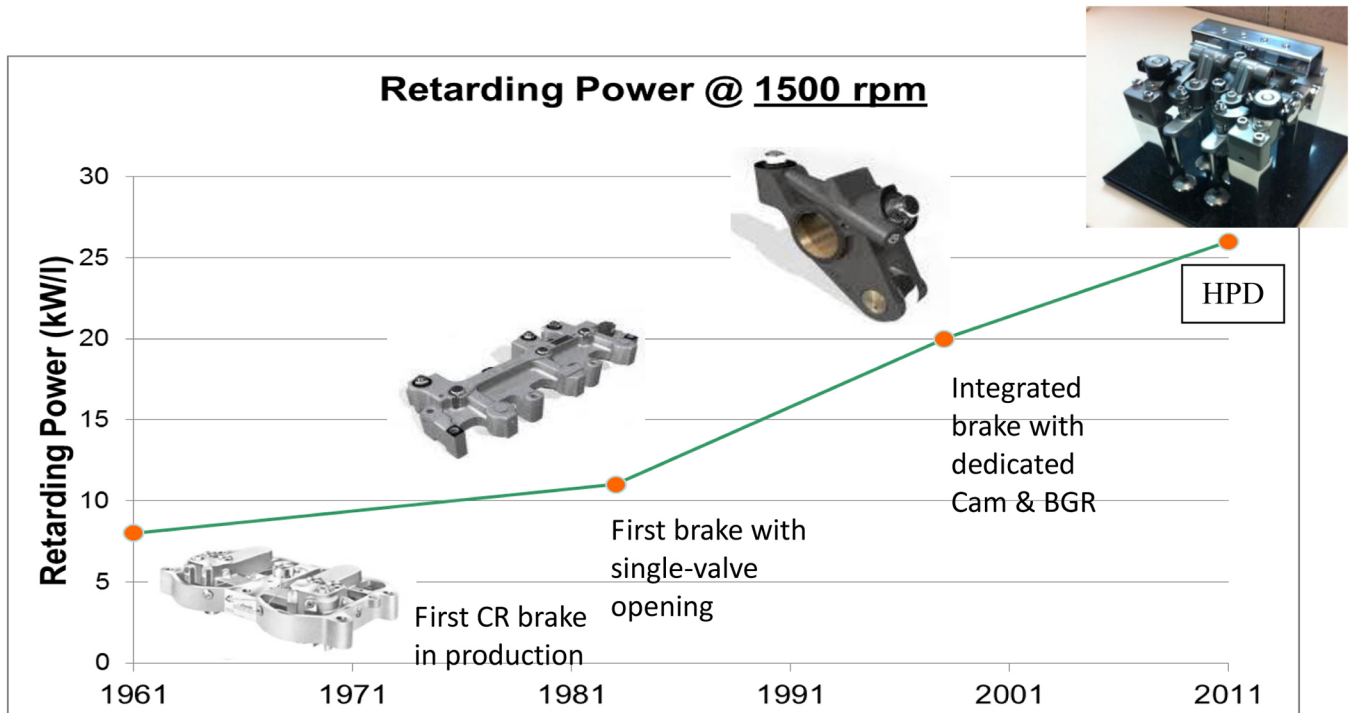


Figure 3. Retarding Power Evolution over time

years earlier than the four stroke braking concept was invented by Clessie Cummins¹. In order to make the two-stroke braking possible, the main intake and exhaust events need to be disabled. Additionally the second CR and second

BGR events need to be placed to operate relative to the *exhaust* TDC and two intake events need to be added so that fresh air is introduced into the cylinder so that there is air mass to compress.

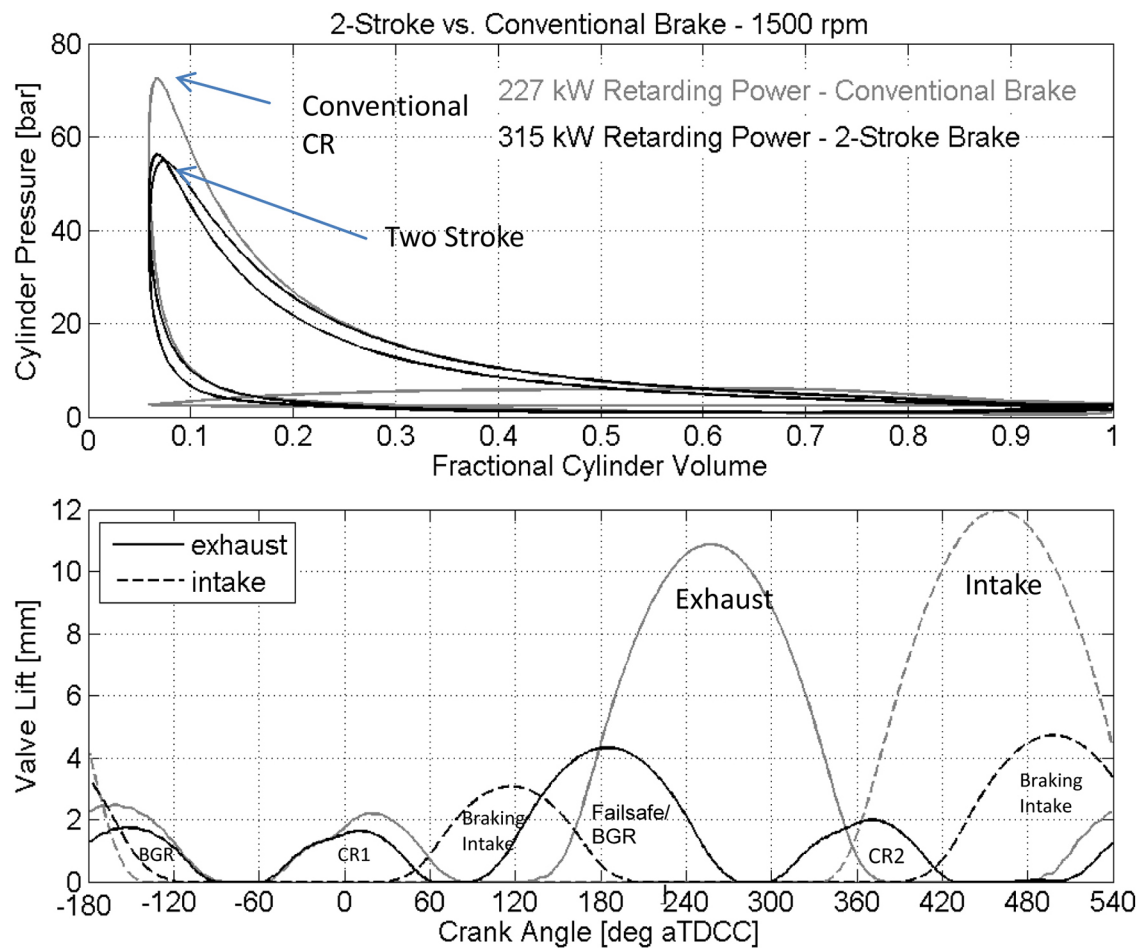


Figure 4. PV Diagram and Valve Opening Events - 2 Stroke Braking

The Jacobs device utilizes two standard “braking rockers” to achieve the braking function on one exhaust valve and the unique intake profile on one intake valve. These two rockers utilize a lost motion function. The system uses a large lash to avoid the cam lift when not enabled. When the braking and intake function are needed, a solenoid valve (not shown) located on the rocker, routes oil to the slave pistons located in the rockers, thus causing the slave piston to extend taking up the lash. Each rocker is thus biased to the cam, transferring the motion from the cam to the relative intake or exhaust valve.

One of the most significant issues with two-stroke braking is the fact that the normal intake and exhaust events must be disabled. Disabling is not a difficult issue, but ensuring that the device being used to deactivate the exhaust event re-engages in a timely and smooth manner has been a critical design task. If the device does not re-engage, there is a risk of engine damage due to high cylinder pressure the next time either valve tries to open.

Previous JVS experience with 2-stroke braking

The energy crisis of the late 70's and early 80's triggered a trend toward more efficient vehicles, including heavy duty commercial vehicles. The overall natural retarding resistance

of the heavy duty commercial vehicles was significantly reduced by a variety of vehicle modifications such as the reduction of air drag, decreased rolling resistance, reduced engine friction, combined with lower engine operating speeds. This resulted in a demand for an increased retarding power from the existing engines.

Jacobs addressed the challenge by improving the compression retarding technology with two parallel developments:

1. Improvement of the four cycle retarding process by optimizing the valve opening event toward reaching the near ideal braking valve opening timing and its rate of opening. The technology is based on the principle of a high pressure common rail¹⁶, utilizing the engine lubricating oil. This accomplished a desirable valve motion independent from the engine cam profile. It reached production release in the late 80's. Despite having “optimal” valve timing for the four-stroke process, this technology did not reach the same potential as that available in the two-stroke braking process.

2. Initially a full two-cycle retarding process¹¹ and hardware were outlined. It turned out to be rather difficult