Venturi Induction for Automotive Fuel Economy and Performance

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ABSTRACT

PRV performance has developed, patented, and tested an automotive air/fuel induction system, to improve engine torque and reduce throttling losses. Improved pre-mixing of fuel and air ensures greater engine efficiency and lowers tailpipe emissions. The Pintle-regulated Venturi induction (PRV) with fuel injection directly at the throat, improves fuel economy and increases torque by

- reducing piston pumping loss;
- pre-vaporizing fuel upstream of the engine, thereby cooling the fuel/air mixture and lowering the mixture density; and
- eliminating fuel stratification on the cylinder walls.

Keywords: fuel economy, greenhouse gases, engine

1 BACKGROUND

The power of a spark ignited engine is directly related to the mass of air flowing into the cylinders. A conventional throttle (Figure 1) regulates the air flow into the engine by imparting a non-recoverable pressure loss upstream of the engine.

Figure 1: Conventional throttle plate.

The throttle plate operates by suffocating the engine from airflow; the throttled engine cannot breathe, and therefore delivers less power. Unfortunately, the restricted air flow causes the engine to labor inefficiently. The work required to overcome the vacuum created by the non-recoverable pressure loss, results in wasted fuel and, consequently, reduces the engine efficiency.

2 THE PINTLE-REGULATED VENTURI (PRV) CONCEPT

Throttle plates are highly effective -- but highly inefficient -- throttling devices. To overcome the inefficiency of the throttle plate, a variable area Venturi has been developed, patented [1], designed, and tested. The resulting design is a Venturi induction system whereby the Venturi area is varied by an axial moving pintle. Consequently, the throttling effect is accomplished by changing the area of the Venturi rather than imparting an unrecoverable pressure loss, as is the case with the throttle plate. The pintle-regulated Venturi (PRV) induction system facilitates flow into the engine, only stopping the air flow near the bottom dead center of the piston cycle.

Figure 2 is a three-dimensional drawing of a PRV induction manifold for a four-cylinder engine. All pintles are withdrawn in parallel as the gas pedal is pressed.

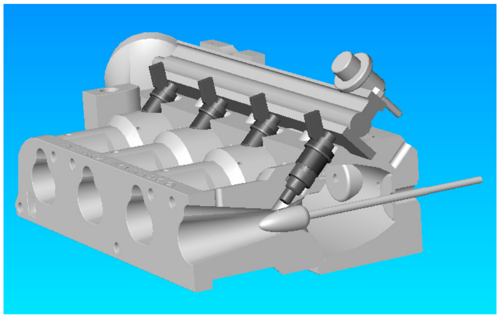

Figure 2 PRV manifold, Venturi 1 cut-away.

The pintle movement along the axis of the Venturi (Figure 4) changes the flow area to provide throttle control of the engine.

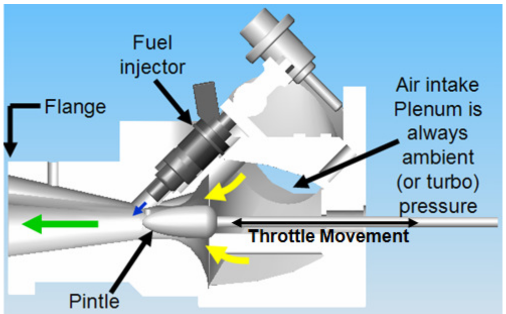

Figure 3**:** PRV cut-away view.

2.1 Improved Pumping Losses

Piston pumping losses can be defined as the non-recoverable work exerted by the piston to pull the charge into the engine and push the exhaust gases out of the engine. The majority of the pumping loss is caused by the force required from the engine to pull the piston downward on the intake stroke. The vacuum caused by a conventional throttle plate causes a large efficiency loss. With a conventional induction system, the pumping loss typically varies from 3.5% at wide-open throttle to nearly 100% for an idling engine [2]. Consequently, while a car is cruising (which is most of the time) the throttle is nearly closed, causing the engine efficiency loss to be substantial.

The pressure profile of a PRV induction system is entirely different for two reasons. First, the PRV intake pressure is always ambient (or turbocharger discharge) pressure. Second, when the cylinder valve closes, air from the plenum can flow around the pintle, equalizing the Venturi discharge pressure with the plenum. There is plenty of time for this to happen, because inlet valves spend at least twice as long closed as open. Third, in comparison with a butterfly throttle which is as obstructive as one could imagine, the PRV is as streamlined as possible.

The throttle control fluid mechanics of a conventional throttle plate and PRV induction system are entirely different, contributing to the improved fuel economy performance derived from PRV. Throttle control with PRV is accomplished by the limitation of sonic velocity at the throat. The velocity at the throat of the Venturi is determined by the speed of the piston, and the annular area between the pintle and Venturi. Initially, the piston moves slowly and air easily flows through the streamlined Venturi. However, as the piston accelerates downward, at some point the air flow through the Venturi approaches sonic velocity. At sonic velocity, the pressure in the intake duct can no longer influence the flow through the Venturi. The Venturi is said to be choked -- in this way, the streamlined PRV controls the power of the engine. Note that flow control only occurs at the end of the intake cycle, and that air flow up to the chokepoint is unrestricted.

The throttle control of the conventional throttle plate is accomplished by non-recoverable frictional loss of the butterfly valve. Consequently, the piston is pulling against full vacuum for the entire down stroke, resulting in substantially higher pumping losses than PRV induction.

The intake pressure from PRV induction pulsates to reduce pumping losses whereas a conventional manifold operates at a steady, but low, pressure (Figure 4).

The streamlined convergent-divergent Venturi nozzle accelerates airflow as the throat is approached and decelerates airflow in the divergent section. Concurrently, as the air slows down, the pressure increases. The pressure recovery process is governed by the conservation of energy, as described by Bernoulli’s principal [3].

$$\frac{v^2}{2} + gz + \left(\frac{\gamma}{\gamma - 1}\right)\frac{p}{\rho} = c \qquad (1)$$

$v =$ *fluid velocity*
$\gamma =$ *specific heat ratio*
$p =$ *pressure*
$\rho =$ *fluid density*
$g =$ *acceleration of gravity*
$z =$ *elevation*

The pressure recovery attribute of PRV improves the piston-pressure history and, consequently, reduces pumping loss.

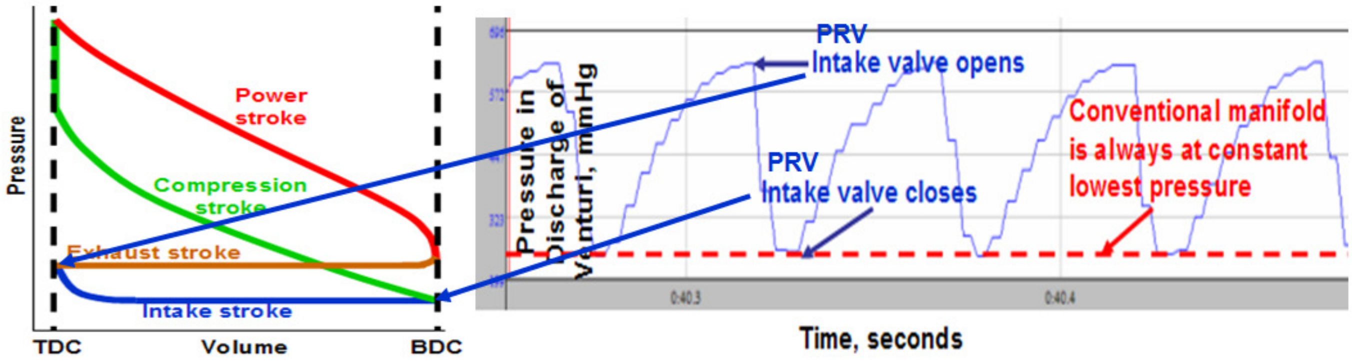

Figure 4: Pulsating pressure profile from PRV induction.

2.2 Torque Improvement from Cooled Charge

With a conventional intake manifold, some of the fuel is vaporized from heat transfer with the cylinder wall. However, evaporation is seldom complete before the intake valve closes [4]. Consequently, efficiency is lost because work is required to evaporate fuel.

The PRV fuel injector is aligned with the throat of the Venturi where the air velocity is at the maximum and the air pressure is at the minimum, thereby thoroughly vaporizing and mixing fuel into the air stream. The fact that the Venturi throat is the low pressure point is counter-intuitive, but consistent with the conservation of energy. The expansion of the vaporized fuel in the Venturi pushes the fuel/air mixture into the engine. Further, a cooler, denser charge improves airflow to the engine, thereby improving torque.

2.3 Reduced Emissions from Cylinder Wall Stratification

Hydrocarbon and CO emissions are produced when the combustion process is not complete. The major source of exhaust hydrocarbons is generated from fuel, trapped inside cylinder crevices, into which the main combustion flame cannot enter. In the exhaust port and exhaust manifold, a portion of the residual hydrocarbons are combusted to CO or CO2 [5]. PRV induction pre-vaporizes the fuel and, consequently, less fuel is trapped in the cylinder wall crevices, thereby reducing hydrocarbon and CO emissions.

3 BENEFITS DERIVED FROM PRV INDUCTION

PRV induction reduces fuel consumption, increases torque, and reduces greenhouse gas emissions -- at no additional cost relative to a conventional manifold system. Consequently, smaller, lighter engines are facilitated with PRV induction, particularly when coupled with a turbo charging system

3.1 Torque Improvement

The prototype car was independently tested on a chassis dynamometer by Revolutions Performance in Colorado Springs, Colorado. The dynamometer testing demonstrated that torque is increased 15-20% on a normally aspirated engine, fueled by gasoline (Figure 5). Further, it is noteworthy that the PRV induction system substantially improves low end torque, thereby improving the drivability of the vehicle.

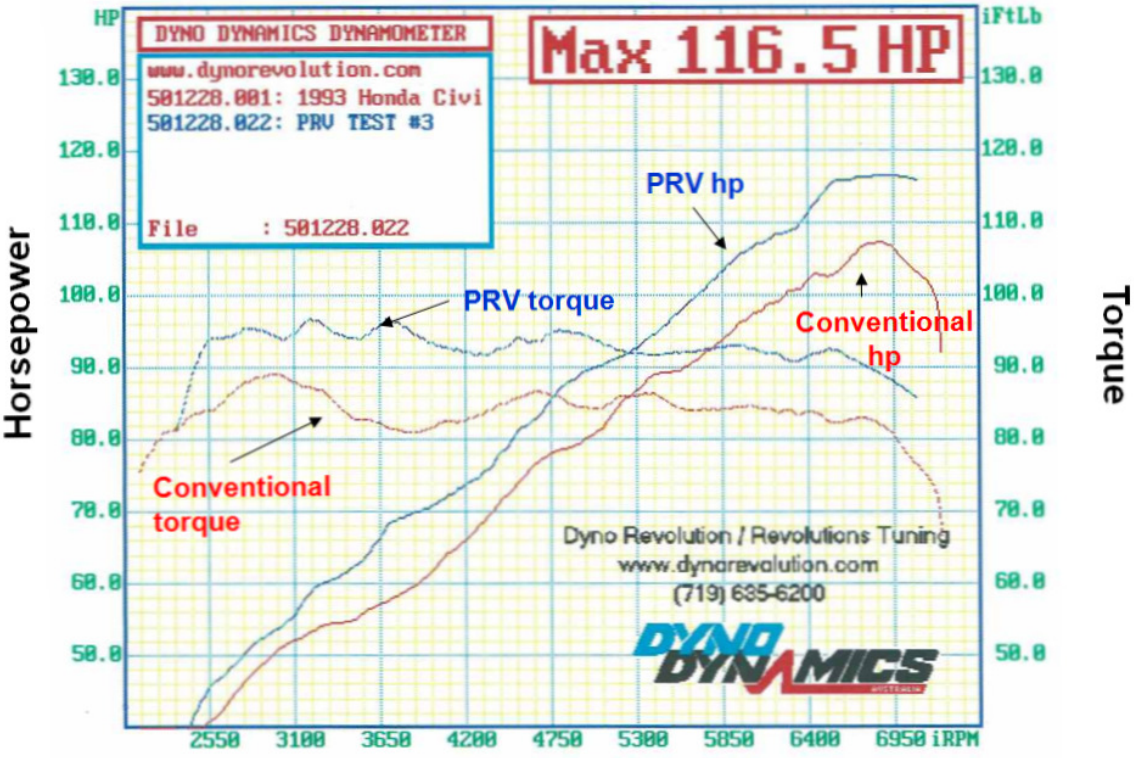

Figure 5: Torque and horsepower of a gasoline fueled normally aspirated engine.

3.2 Fuel Economy Improvement

The inventor has adapted a prototype PRV induction system into a Honda Civic. Prior to all testing, the engine was replaced with a Honda D15B engine. The tires were upgraded to low rolling resistance Sumitomo tires.

Ten prototypes have been driven and tested for over 25,000 miles. Fuel economy comparisons have been made in both city and highway driving. The highway test is a 204 mile closed-circuit test loop between Denver, CO and Brush, CO. There were no mechanical changes between tests other than the induction system. The conventional manifold tests used a stock Honda computer control unit. The prototype uses an AEM Power computer control unit. The computer control unit was changed only because the PRV induction system, with the pulsating pressure profile, requires a mass airflow control unavailable on the stock control unit. The engine was tuned to operate at stoichiometric conditions. Both the conventional and PRV systems operated in closed loop feedback control from the oxygen sensor.

Four highway tests with a conventional intake manifold, at a steady speed of 65 mph, yielded an average of 43 miles per gallon. The identical test loop was repeated four times with the PRV manifold, again at 65 mph, demonstrating an average fuel economy of 53 miles per gallon. The city cycle mileage improved from 38 miles per gallon to 42 miles per gallon. The large improvement in the highway mileage is attributed to the nearly closed throttle position of steady-state driving, where the PRV induction system delivers the largest benefit.

3.3 Ethanol-Fueled Engines

Ethanol is more difficult to disperse from a fuel injector because of the higher viscosity. Ethanol also has a lower vapor pressure and a higher heat of vaporization. Consequently, with a conventional fuel injection system, more of the fuel evaporation (in comparison to gasoline) will occur during the compression cycle. Conversely, the higher heat of vaporization of ethanol means that pre-mixing of ethanol by PRV lowers the charge mixture more than gasoline. The lower charge temperature and improved dispersion upstream of the engine, provided by PRV, is exactly what an ethanol-fueled engine needs for improved power.

3.4 Emissions

PRV induction reduces exhaust emission of CO2, CO and unburned hydrocarbons. A conventional fuel injection system sprays droplets into the cylinder. Some of the droplets impinge on the cylinder walls. Those impinged droplets become entrained into crevices in the cylinder wall, resulting in incomplete combustion of the fuel and the generation of CO and unburned hydrocarbons. CO2 reduction is accomplished by improving fuel economy.

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