

LOW COST ELECTRONIC FUEL INJECTION FOR MOTORCYCLES AND UTILITY ENGINES

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ABSTRACT

As a result of environmental pressures and end-user demands several companies are working on low cost fuel injection systems specifically for small motorcycles and utility engines.

A common approach to this application is to take an existing engine management system derived from automotive or high end motorcycle applications and to re-design it to reduce its complexity and cost for the small engine market.

This paper introduces and discusses the latest development and application of a novel engine management system designed from the outset specifically for low cost small engines for motorcycles and utility applications (Pulse Count Injection, PCI [ref 2, 3]).

The paper details comparisons of the performance of the PCI system compared to carburettor and conventional EFI systems.

Detailed results are shown for;

- Fuel consumption comparison
- Engine out emission benefits
- Fuel flow comparison
- Cost reduction

The paper demonstrates the latest state of development of the PCI system technology.

Conclusions are drawn from the test results showing the clear benefits of PCI fuel injection for both emissions and fuel consumption reduction when compared to carburettor systems. The paper also demonstrates that PCI performance is comparable to state-of-the-art small engine EFI system but available at half the cost.

INTRODUCTION

As a result of environmental pressures and end-user demands several companies are working on low cost fuel injection and engine management systems for small motorcycles and utility engines, which as a global market represents approximately 100 million new engines produced annually [ref 1].

Pulse Count Injection (PCI) [ref 2, 3] is a new and novel low cost high frequency fuel injection system designed specifically for the small engine market.

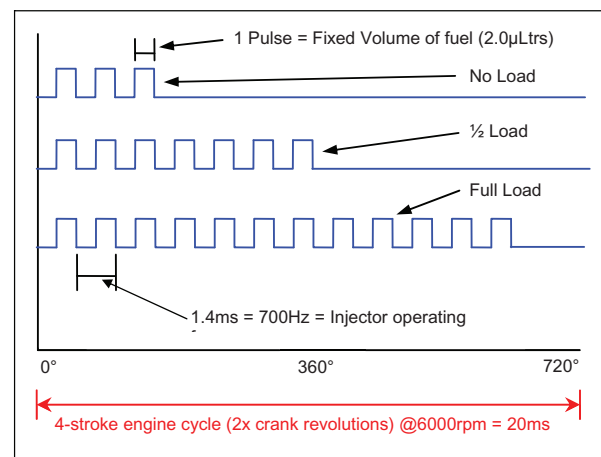


Fig.1 Graphical representation of Pulse Count Injection for a 700Hz injector running on an engine at 6000rpm under different load conditions.

PCI is based around an injector that operates as a positive displacement pump. The piston in the injector oscillates at high frequency, typically 700Hz. Each time a piston oscillation occurs a fixed volume of fuel is delivered from the injector to the engine. This action is performed a controlled number of times every engine cycle with the number of pulses injected being dependant on engine load and speed. For example, as shown in Figure 1, under engine no-load conditions 3 pulses of fuel will be injected every cycle whilst under full load 12 pulses will be injected every cycle.

By controlling the fuel flow and injecting fuel in this unique high frequency manner the whole fuel handling system can be consolidated and miniaturised. The injector shown in figure 2 performs all the functions of the conventional fuel pump, pressure regulator, and injector metering device and can also be used as a feedback sensor capable of determining the exact amount fuel it is pumping.

A medium flow injector operating at 700Hz can deliver 2 μ Ltrs per pulse giving a maximum flow rate of 5ltrs/hr. A minimum of 0.8 μ Ltrs and a maximum of 2.6 μ Ltrs per pulse can currently be specified by altering the piston stroke.

The electrical power consumption for the injector (no additional pump required) at full load condition, shown in figure 1, is only 6 Watts. And under idle conditions when only three pulses per cycle are being used at 1500rpm the power consumption is only 0.4Watts. The ECU itself consumes 0.6W.



Figure 2. Pulse Count Injector shown with small (Ø18mm) coin.

The PCI system does not require a pressurising pump and as a result does not need high pressure fuel pipes. To be fully functional the injector only needs a reservoir of fuel around it, and on applications where there is a head of fuel due to the positioning of the tank (e.g. on a motorcycle) only a simple supply pipe and vent pipe arrangement is necessary. If the fuel tank is below the injector a simple crankcase driven diaphragm type fuel pump is required.

By using such a high frequency system much of the cost of a conventional fuel injection system is either reduced or removed. The reduced parts count allows connection simplification and direct mounting of the ECU on to the throttle body.

The following sections of this paper compare the operational performance of the high frequency PCI system with a conventional carburettor, typical of the small utility engine market, and with a state of the art Electronic fuel injection system from a 125cc motorcycle.

COMPARISONS OF PCI WITH CARBURETTOR ON A UTILITY ENGINE

The following test results are a comparison between a 19hp V-Twin utility engine fitted with a PCI engine management system compared to its original carburettor fitment. This testing gave very good indications to the improvements that can be made to a utility engine with a fully programmable fuelling system compared to the originally carburetted engine. To ensure the tests were a valid comparison of fuelling systems alone the ignition system was left as the standard flywheel energised coil for both cases. The test engine fitted into the test cell is shown figure 3.

The engine is capable of running lambda 1 at mid-load conditions and close to lambda 1 at idle and is representative of many carburetted motorcycle and utility engines.

Baseline tests were carried out on it with the original carburettor and then the PCI engine management system was fitted and tested.

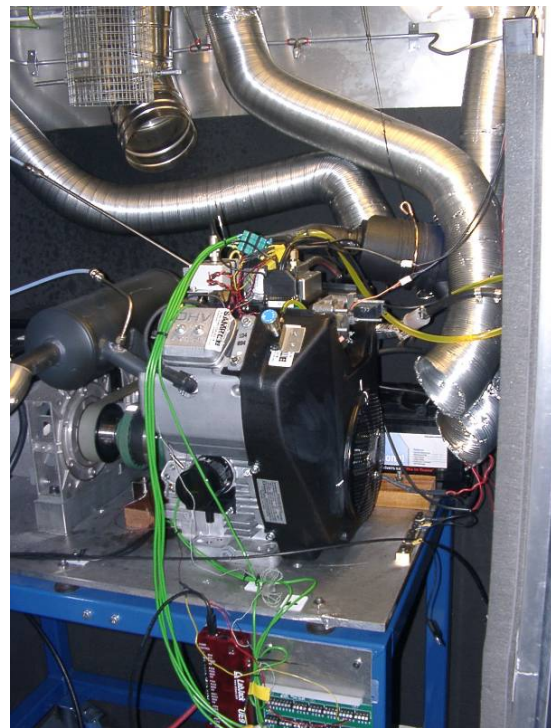


Figure 3. 19Hp V Twin engine with PCI system fitted in dynamometer test cell.

The fuel consumption comparisons, shown in figure 4, were measured on the engine dynamometer shown in figure 3. The fuel weights shown were taken at different engine load settings at a constant engine speed of 3200rpm, and were taken for both the standard carburettor and for a range of PCI engine management settings.

Figure 4 shows 3 or 4 fuel consumption bars for each of the 6 load conditions. In all cases the red bar is the fuel consumption figure for the standard factory fitted carburettor condition. The blue and green bars are different fuelling conditions with the PCI fuelling system. Where a green bar is present (load conditions

75%, 50% and 25%) this indicated the engine was operated at lambda 1 with the PCI system, and where a green bar is not present it indicates the engine was not capable of stable lambda 1 operation, and therefore the lean limit operation indicated by the dark blue bar is still richer than lambda 1 for that condition.

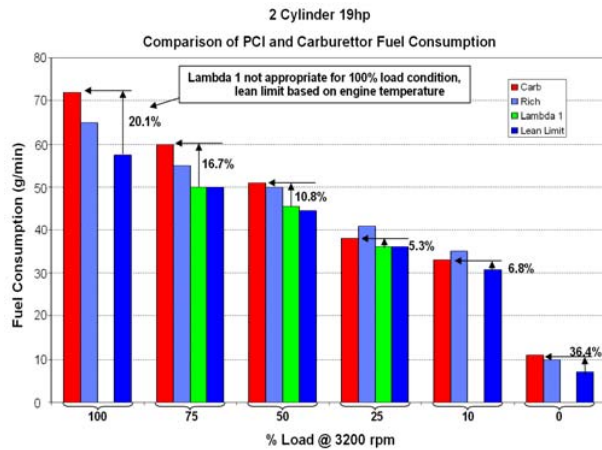


Figure 4. Fuel consumption comparison data at 3200rpm

As would be expected with a fully programmable fuelling system the PCI fuel flow can be precisely mapped for all engine conditions, allowing the optimum combustion settings to be chosen for each condition, whether this is rich operation at high load to control the engine temperature, or lean operation at mid-load to minimise emissions, or again slightly rich at idle to achieve stable combustion.

The fuel consumption savings at these different test points varied from 5% to over 30%, and clearly demonstrates considerable fuel economy improvements are available by the introduction of electronically controlled fuel systems.

As well as optimised fuel mapping, precisely controlled fuel delivery ensures minimum air fuel ratio (AFR) variability from cycle to cycle. Figures 5 and 6 show the AFR (shown as lambda reading) measured with exhaust sensors for both cylinders of the engine for the carburettor and PCI fuelling systems respectively.

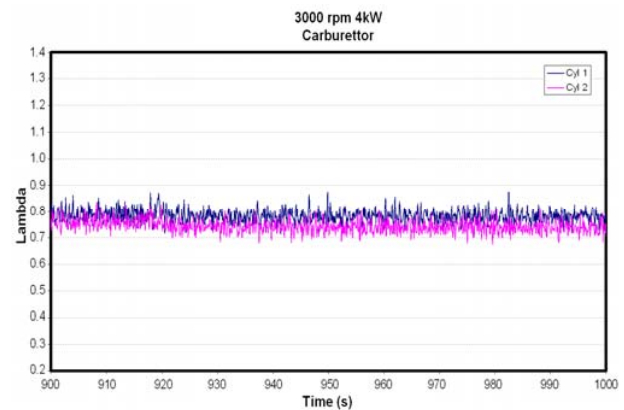


Figure 5. Carburettor cycle to cycle variability and cylinder to cylinder AFR variability.

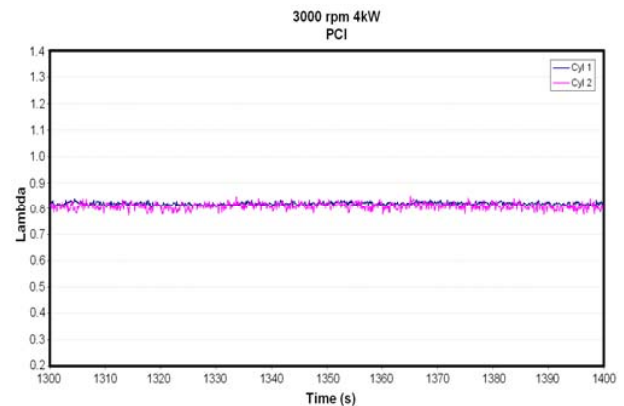


Figure 6. PCI cycle to cycle variability and cylinder to cylinder AFR variability.

Figure 5 shows the carburettor has greater AFR fluctuations cycle to cycle than the same engine conditions (3000rpm & 4kW) when running with PCI system shown in figure 6 at the same average Lambda setting. It can also be seen that there is an off-set of Lambda between the two cylinders when running with a carburettor (figure 5). This is due to cylinder air robbing occurring upstream of the carburettor. With PCI this has been adjusted for and as a result each cylinder runs much closer AFR's.

Engine out emissions were also recorded with an Oliver IGD – Tocsin 320 multi gas analyser over the range of engine load conditions and compared in figures 7, 8 & 9.

In figure 7 the Carbon-monoxide (CO) output of the engine is compared between running on its factory set carburettor (shown by the red line) and the PCI system, (potential PCI fuelling capability shown by blue hatched area).

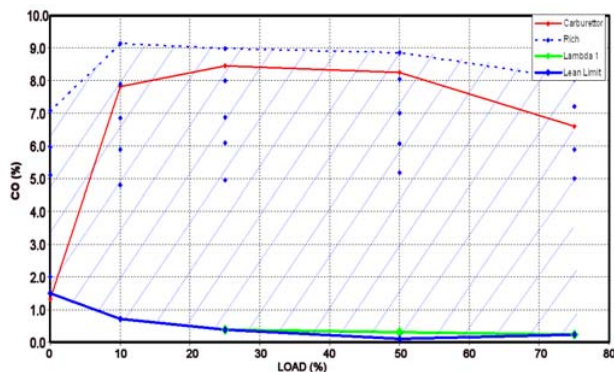


Figure 7. CO results for V-Twin running on carburettor and PCI at 3200rpm.

The potential operating range of the PCI system shown in figure 7 clearly shows that the engine, if capable, can be made to run at Lambda 1 (shown by the green line) or at its leanest operating point when using PCI. The large blue hatched area below the red (carburettor) line shows the very large potential for reducing the CO emissions output of engines by fitting electronic fuel systems and optimising the fuelling at all conditions.

Figure 8 shows a similar graph to figure 7 but in this case with the emission gas being HydroCarbons (HC) which were measured with a Hexane Infra red sensor.

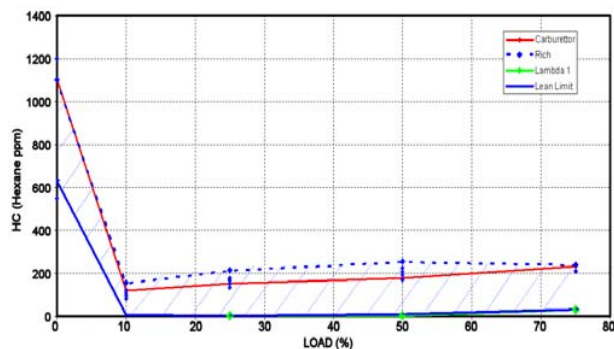


Figure 8. HC (Hexane) results for V-Twin running on carburettor and PCI at 3200rpm.

Like the CO graph the HC graph in figure 8 also shows a very significant opportunity to reduce engine out emissions from the carburettor level (red line) over the entire engine operating range

Figure 9 shows the Nitrous Oxide (NO) emissions for the engine. In this case the carburettor results (red line) are low as the rich operating condition of the carburettor restricts NO formation during combustion.

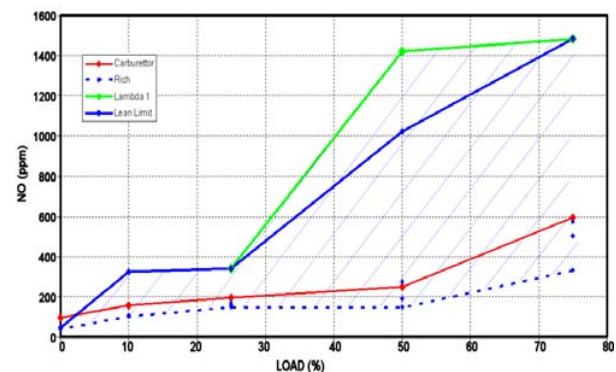


Figure 9. NO results for V-Twin running on carburettor and PCI at 3200rpm.

By choosing optimum operating conditions with the PCI system at each load condition the overall emission results (as weighted by EU standard [ref 4]) can be reduced when compared with the original carburettor system by the amounts shown in table 1.

Emission	Carburettor	PCI system	Reduction
HC	9.048	1.480	83.6%
NO	2.490	5.934	-138.3%
HC + NO	11.538	7.413	35.8%
CO	345.292	40.448	88.3%

Table 1. Weighted emission results comparison

COMPARISONS OF PCI WITH CONVENTIONAL PULSE WIDTH MODULATED FUEL INJECTION ON MOTORCYCLE ENGINE

As discussed in [ref 5,6,7,8] there are a number of Pulse Width Modulated (PWM) pressurised fuel injection systems currently being developed for use on small engines. With the exception of ref 8, most of these systems are adapted or derived from the technology used in automotive systems. This means the systems comprise a high pressure fuel pump and pressure regulator to control the fuel pressure at an accurate preset value and an injector (housed in the throttle body) which controls the flow of fuel into the engine by a variable duration (width) pulse.

As can be seen in figure 10 the fuel handling system of a PWM system is a complex and hence expensive multi component system. Whilst the Pulse Count Injection (PCI) system has a simple low pressure feed and vent line directly from the tank to the PCI injector (housed in the throttlebody) with no other parts required, keeping the overall system cost to an absolute minimum.