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The Bruntel planetary disc extended expansion 2-stroke engine with variable valve control

K. Hall

Bruntel Limited, Maidenhead, Berkshire SL6 3PF, UK

Abstract

A low compression / high expansion ratio spark ignition engine strategy is proposed as a means of achieving ultra low exhaust emission vehicles using a low octane non carcinogenic fuel. Predicted fuel economy is better than a direct injection Diesel engine. Variable capacity capability by means of pulse valve control together with stratified charge mixture control determine the performance output via a fully balanced compact drive mechanism.

1. Introduction

The thermal efficiency of automotive engines has been limited since their inception over a century ago by common compression and expansion ratios of fixed volume. Part load efficiency is limited with the Diesel engine due to friction resulting from high levels of compression work and with the spark ignition engine due to intake throttling. Essential ingredients for an internal combustion engine capable of meeting future emission and fuel consumption requirements are likely to include the following:

1. A high expansion ratio for maximum temperature drop of the working fluid,
   a. to achieve optimum thermal efficiency,
   b. to minimise CO_2 emissions,
   c. to reduce exhaust noise.
2. A low compression ratio,
   a. to minimise negative work - friction,
   b. to lower peak temperature - reduced NO_x emissions,
   c. to reduce knock sensitivity - lower octane number,
   - eliminate fuel carcinogens.

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3. Spark ignition to fire the low compression charge.
4. Lean burn stratified charge control,
    a. to minimise NO_x, HC and CO emissions,
    b. to modulate engine output.
5. Variable capacity engine control,
    a. to increase part load efficiency - eliminate intake throttling,
    b. to increase torque back up - driveability.

2. Pulse Valve Solution

Pulse valve control allows the start of compression to be changed in order to vary the effective engine operating capacity whilst retaining the optimum expansion ratio. The Bruntel solution described in this paper (patent pending) uses solenoid activation / control of the exhaust valve in combination with an inlet valve that opens in response to cylinder depression. Hence, the induction phase automatically follows the exhaust phase without the need for camshafts or drive mechanisms. Pulse tuning phenomena are applied to the exhaust process to evacuate the cylinder and reflect the outgoing positive wave back from the expansion box creating the necessary cylinder depression to trigger open the inlet valve and initiate induction. Pulse tuning is also applied to the induction system , with the negative wave being reflected from the intake plenum back into the cylinder as a positive charge. Normally, variable length pipes would be required to optimise the pulse tuning at each speed, but by employing a fixed solenoid pulse period the engine is optimally tuned for all speeds using conventional fixed geometry manifolds.

With such a robust pulse tuned system it is not necessary to employ the extra revolution for induction used by the 4-stroke engine or the crankcase compression of the 2-stroke engine. Instead the expansion phase occupies the power stroke with exhaust, induction and compression phases occupying the return stroke. The intake system may be pressure charged. Such a 2-stroke cycle is only suitable up to half the speed of the typical 4-stroke automotive engine before it runs out of sufficient crank angle to accommodate the three phases in the return stroke, but this simply restricts operation to the quietest most efficient speed range.

Cylinder Head

Figure 1. shows a low compression cylinder head arrangement capable of operating as described. A compact chamber and late fuel admission are selected to enhance the low octane capability. Such a low octane design should allow the fuel scientist to eliminate high octane carcinogenic agents from the fuel. The spark plug is arranged centrally in the cylinder with concentric annular inlet and exhaust valves encircling it. The double seats of the annular valves offer very large areas and rapid rates of opening required to achieve rapid pulse charging. The exhaust valve is outermost and activated by a pair of

solenoids. The inlet channel feeds two annular inlet valves which are spring loaded to respond to differential pressure, the innermost valve feeding the fuel rich mixture into the central core of the cylinder under the spark plug, achieving radial segregation from the exhaust port. Guide vanes pressed into the annular inlet ports provide precision turbulence generation for optimum combustion and support the light inlet valves against combustion pressure. Such a pulse valve system is controlled by the exhaust solenoids with fuel quantities adjusted accordingly via port injection.

Variable Capacity

Engine working capacity is decreased by simply retarding the exhaust solenoid timing, or increased by advancing it. As engine speed falls so the capability to increase capacity rises. Such a characteristic reduces the number of transmission gears required. Figure 2. shows five modulation scenarios across the engine load / speed range.

Urban Economy

The urban mode (low load / low speed / weak stratified mixture) operates most efficiently when the highest peak temperature is generated for a given net cycle work. This implies the lowest charge mass (small engine capacity), lowest engine speed and highest temperature drop for the given work condition. With full expansion approaching atmospheric pressure, and compression capacity / engine speed selected to achieve the highest operating temperature, the pulse valve engine is predicted to offer substantially higher urban economy than the best Diesel. The fully balanced planetary disc drive mechanism described later enables the low engine speeds to be achieved without increased harshness. At low engine speeds and low loads, exhaust, induction and compression account for only a proportion of the return stroke. Similarly, the total swept volume is larger than the full expansion volume required. The solution is to continue expansion to bottom dead centre and then recompress until the pressure has returned to just above atmospheric before opening the exhaust valve. The losses entailed in such a process are small compared to throttling losses or the high compression / friction losses of the Diesel.

The weak stratified mixture combined with the precision concentric combustion process endows the engine with ultra low emission potential. The lower compression ratios (excluding the capacity boosted condition) contribute significantly to the engines ultra low NO_x potential. The engine is also likely to be far more tolerant of spark retard because of the extra expansion volume available.

Cruise Economy

The typical cruise condition of half load / half speed is able to use the large engine expansion capacity to fully expand the combustion products, eliminating the critical exhaust pressure ratio which causes supersonic exhaust flow and high exhaust noise. The extended expansion combined with the advantageous

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work ratio as a result of the small amount of compression work (Atkinson cycle) endows the engine with predicted brake thermal efficiency higher than the best direct injection automotive Diesel engine. While full expansion is maintained, efficiency increases as the peak temperature is increased, i.e. as engine load increases.

High Torque

If more torque is required, for example to climb a gradient, the exhaust solenoid timing is advanced by demand from the accelerator pedal, increasing the effective engine capacity and increasing the air / fuel ratio towards stoichiometric. At lower engine speeds a larger effective capacity is achievable because the fixed exhaust and induction phases account for a much smaller proportion of the crankshaft revolution. This characteristic of rising torque with falling speed more closely matches vehicle torque requirements, making the vehicle easier to drive and requiring fewer transmission gears. In high torque mode the efficiency benefits of extended expansion are sacrificed to meet the extra performance requirements. Even so the brake thermal efficiency is predicted to match the highest levels attainable by current spark ignition engines.

The non carcinogenic octane number is likely to determine the level of capacity boosted torque available.

High Power

In the acceleration mode of high power (high load / high speed / stoichiometric mixture) the expansion volume is cut back in order to accommodate a like compression volume. Thermal efficiency is predicted to remain equivalent to current spark ignition engines of similar expansion ratio. With like efficiency and like power strokes per minute as 4-stroke engines maximum performance is predicted as being similar, assuming like volumetric efficiencies.

Downhill

The flexibility of pulse valve control enables the engine to function as a brake for downhill situations. Fuel is cut off and the exhaust timing fully retarded. Now the cylinder itself produces the depression necessary to trigger open the inlet valves and draw in air. The return stroke is used to compress the air and exhaust it. This is a useful additional means of braking.

3. Disc-Yoke Connector

Propulsion system weight and package volume plays a significant role in influencing the overall vehicle efficiency. As a result a disc-yoke mechanism for converting linear to rotary motion is proposed which markedly reduces engine weight and size (Figure 3.). A planetary disc and piston yoke replace the conventional connecting rod. The coupling of a second disc - yoke at 90 degrees to the first on a common crankpin results in a constant radial inertial

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force through the crankpin and crankshaft axes at all crankshaft angles. This force is equivalent to the reciprocating mass of one cylinder line acting radially at the centre of the crankpin. Inertial torque is completely eliminated because of the radial direction of the inertial force. Complete counterbalancing of primary forces and couples is achieved by lightening holes close to the outer diameter of the flywheel and front pulley.

The throw of the crank and planetary disc are each one quarter of the stroke and counter-rotate at constant angular velocity producing simple harmonic motion. Hence, higher orders of imbalance are eliminated. Yoke guides react side loads in the yoke, eliminating piston side loads for conditions of concentric combustion and thus the requirement for piston skirts. This results in an extremely compact crankcase assembly and eliminates side loads from the removable cylinder barrels. The crankshaft is stiffened by through bolting of the crankpin and this facilitates engine assembly.

Propulsion system smoothness is predicted as better than existing 6 cylinder 4-stroke engines.

Bearing Friction

The oil channels in the planetary discs are also used to control bearing area at each angular position of the crankshaft according to a constant bearing pressure strategy. A small crankpin area results from the stiff short throw crankshaft and long shared bearing length. These factors together with roller main bearings and elimination of piston skirts achieve a quantum reduction in engine rubbing areas which more than offsets the higher side forces experienced by the piston yoke compared to the piston skirt.

Ancillaries

Ancillary drives have been considerably simplified by adopting a concentric flywheel / starter / generator where the rotor is also the flywheel mass (Figure 4.). Such a concept offers the additional potential of regenerative braking to be integrated into the control strategy. It is also proposed to use oil cooling to simplify the vehicle package. The powertrain would be light enough for the vehicle not to require power steering.

Package

The V4 engine shown in Figure 4. easily packages in a front wheel drive vehicle either north / south or east / west and provides a firing pulse every 90 degrees for smoother operation. The power density target is 1kW/kg which exceeds the best volume production performance engines. The energy density of. lead acid battery propulsion systems are typically 40 fold worse than standard spark ignition systems.

Further Bruntel proposals for a safer / lighter vehicle concept are beyond the scope of this paper.

4. Summary

The Bruntel planetary disc extended expansion 2-stroke stratified charge engine with pulse valve variable capacity control offers improved vehicle economy from idle up to the capacity boosted full load performance condition through improved thermodynamics and control strategies. Urban and cruise modes benefit most. Better matched torque characteristics improve driveability.

The reduced sensitivity to octane number as a result of the low compression ratio regime offers the opportunity to eliminate carcinogenic fuel blends and improve refinery efficiency levels. The low compression regime also implies low NO_x emissions and lean burn stratified charge offers ultra low levels of NO_x, HC and CO. The improved thermal efficiency and low idle speed equates to reduced CO_2 emissions without the particulate emissions associated with Diesels. The emissions signature is of a propulsion system with the potential to meet ultra low emission vehicle standards without resort to expensive package unfriendly after treatment devices.

The disc - yoke connector mechanism offers smoother reciprocating propulsion systems with ultra low idle speed potential and outstanding weight and package reductions.

In comparison a battery propulsion system requires further technological breakthroughs to make its range, performance and efficiency anywhere near comparable.

Such a pulse valve propulsion system merits serious consideration for all forms of urban transportation because its environmental credentials are so attractive and the solution is based on known technological principles.

Internal combustion propulsion systems are unlikely to meet zero emission criteria even if the hydrocarbon fuel were replaced by hydrogen, as such a fuel is still likely to produce NO_x emissions.

A hybrid propulsion system with limited range and performance in the zero emission mode is one solution for densely populated environments. The pulse valve engine with its integral starter / generator and reduced weight / package volume is ideally configured to meet this challenge simply by enlarging the generator and adding the necessary battery power.

The pulse valve engine epitomises simple efficiency, essential ingredients for all transportation systems, from the smallest to the largest.

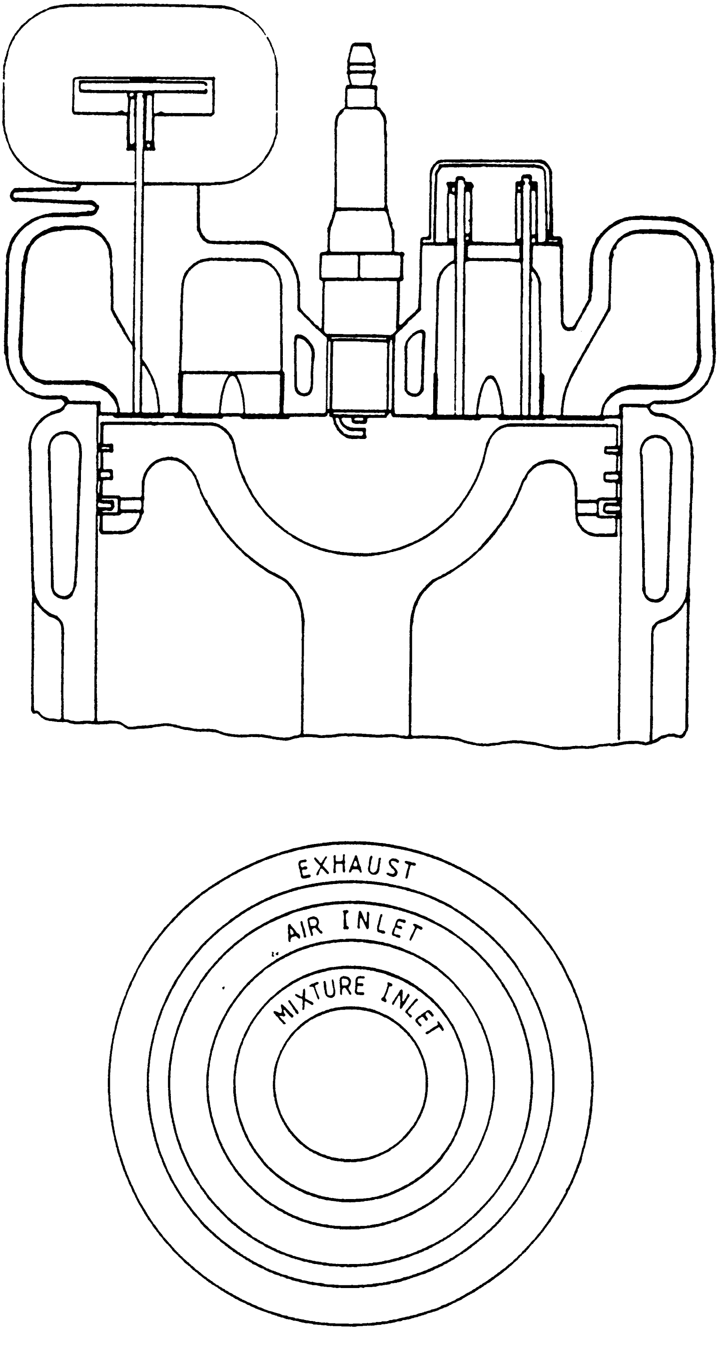

Figure 1: Annular pulse valve low compression cylinder head.

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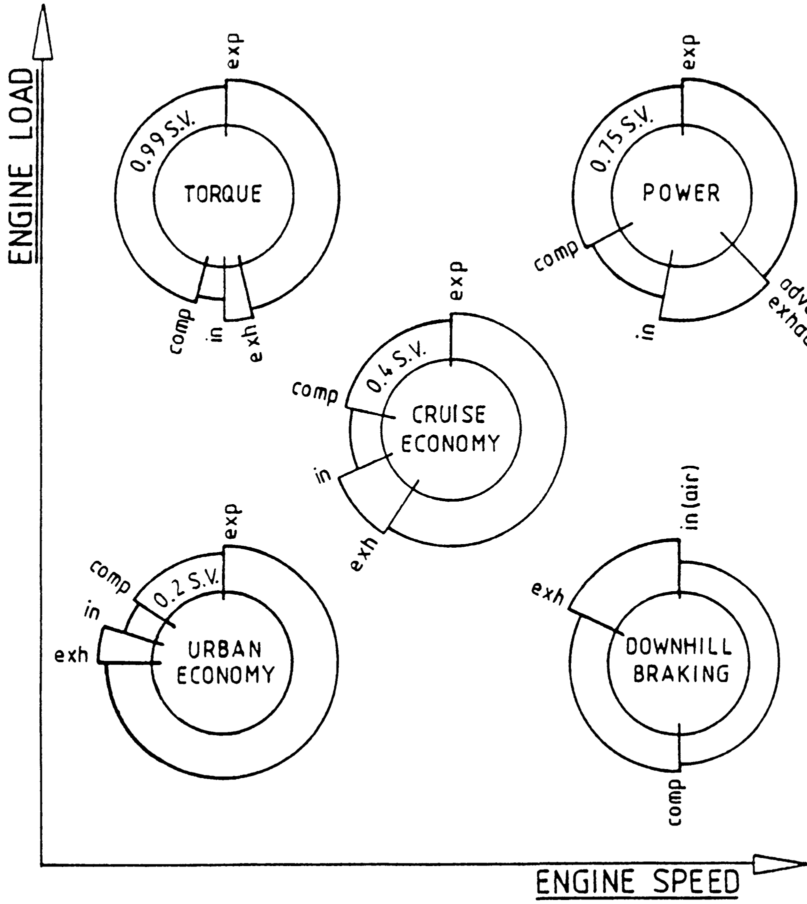

Figure 2: Load - speed effects on valve timing and capacity.

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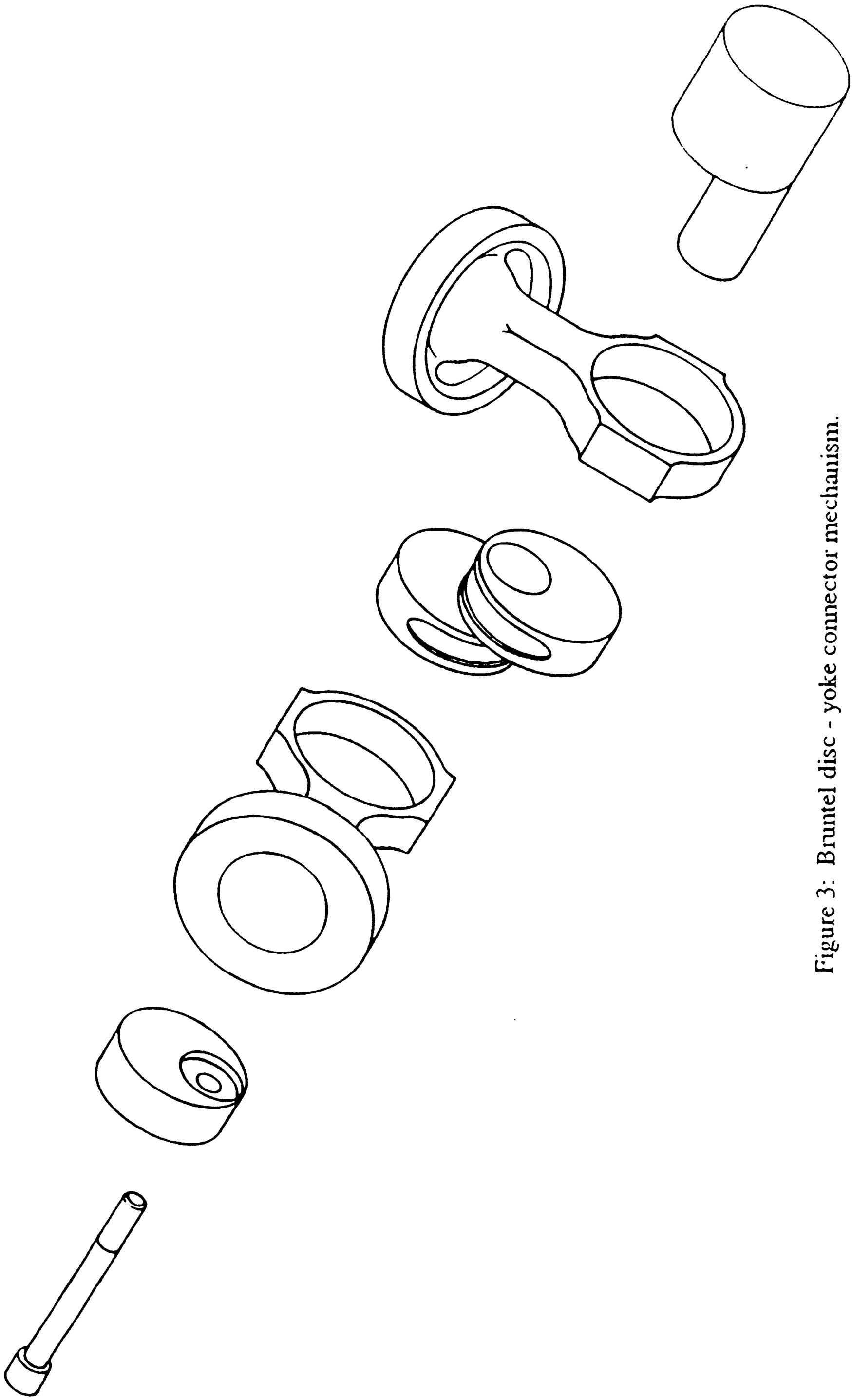

Figure 3: Bruntel disc - yoke connector mechanism.

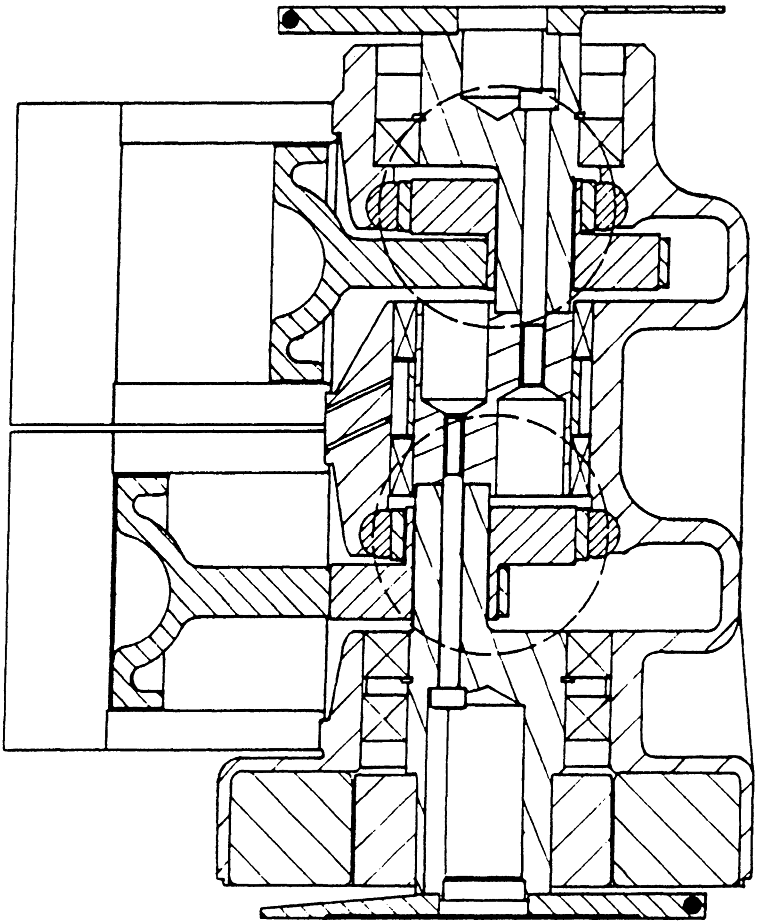

Figure 4: Brunel V4 disc - yoke engine.