# Local Development of a Production Process for Replacement Cylinder Head

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## ABSTRACT

Several constraints exist in the local market as regards the purchase and after - sales services of small stationary diesel engines used for flour milling, water pumping and generation of electricity. These constraints could be substantially addressed through local production of frequently used spares. This paper describes the local development of a production process for a cylinder head of a single cylinder diesel engine.

The design drawings were used to design the pattern and core box, to mould and make the core assembly which were subsequently dried in an oven before pouring of molten metal. The cylinder head manufactured by the process was pressure tested for integrity of the water jackets and ports before machining and actual engine tests. The performance of the cylinder head during the on load and no load tests were considered normal.

**KEY WORDS:** Production, cylinder head

## 1.0 INTRODUCTION

The purpose of internal combustion engine is the production of mechanical power from the chemical energy contained in the fuel. In internal combustion engines as distinct from external combustion engines, this energy is released by burning or oxidizing the fuel inside the engine.

As a prime mover the internal combustion engine has found wide application in transportation on land, sea and air and in power generation. For use in transport, the engine power requirement ranges from approximately 2.0 Kilowatts (kW) as for lawn mowers to 400 kW in the case of heavy commercial vehicles. While the power range of stationary engines is however much wider, that is, from 7 kW to 22,000 kW (Heywood, 1988). And in the developing countries, stationary engines at the lower end of the range find typical applications in power generation, water pumping and flour milling.

Internal combustion engines are also classified according to the method of ignition. In spark ignition engines the air and fuel are usually mixed together in the intake system prior to entry to the engine cylinder, using a carburettor or fuel injection system. An electrical discharge across the spark plug starts the combustion process.

In compression-ignition engines, air alone is inducted into the cylinder. The air is then compressed to a high pressure and temperature and towards the end of the compression process, fuel injection into the cylinder begins, the liquid fuel evaporates, its vapour mixes with air to within combustible proportions and spontaneous ignition occurs to initiate the combustion process.

Of the two types of engines, and for stationary applications of power generation, water pumping and flour milling, the compression ignition type is preferred. The diesel engines, as they are often called are robust and when properly maintained have longer life even when working in arduous conditions (Lowry, 1990).

With the liberalization of the national economy the variety of stationary diesel engines presently imported into the local market has greatly increased.

On account of the excessive variety most dealers have been unable to avail conveniently located after sales service centres. This has resulted in high purchase and maintenance costs for this most basic engine.

It is anticipated that local production would offer the following advantages:-

i) Provide more convenient and accessible centres for initial purchase and after sales service.

ii) Encourage the development of maintenance know-how in the local garages.

iii) Maintain control as to the nature and timing of design changes.

This paper focuses on the local development of a production process for a cylinder head for a diesel engine. The focus on the cylinder head was based on the fact that it is considered as the most critical element in engine design and production, since it combines problems of structure, heat flow and fluid flow in a complex shape (Taylor, 1985).

## 2.0 DESIGN SPECIFICATION

The general design of a cylinder head is governed by factors quite other than strength. The air and the exhaust passages must be provided for, the valves and their gear accommodated. The fuel injector normally located near the centre of the head must be provided with adequate cooling.

The central problem in valved cylinder head design is to achieve an arrangement satisfactory from the point of view of valves and ports, which will carry the gas loads and at the same time avoid excessive distortion and stress due to temperature gradients and also avoid excessive high costs or undue complexity (Taylor, 1985).

The present design employs a box section which accommodates the ports and the water space around them. The cooling water which is fed at the bottom exits at a higher level on the opposite side.

Subsequent to sizing of the valves and ports, the design of a cylinder head is largely acknowledged as a drawing board matter. To accommodate the innumerable functional components, a solution usually involves long hours of exploration of varied options.

A direct injection system with combustion chamber as a shallow bowl in the crown of the piston was selected to allow simple cylinder head design. The combustion system is categorized as of medium swirl type with a centrally located nozzle injector.

The air swirl generated by the inlet port is amplified by the bowl in the piston. The generated swirl is used to obtain much more rapid mixing between the fuel injected into the cylinder and the air than would occur in the absence of the swirl (Lowry, 1990).

A cross-sectional view of the engine through the cylinder head, cylinder and piston assembly (Fig. 1) illustrates the main features of the present design. Additionally, a photograph of the engine (Fig. 2) shows the assembled engine as set for no load bench tests.

### Valves and valve Guides

Both inlet and outlet ports are of circular section and located within the cylinder head. The poppet valves are vertical and are slightly offset to one side of the cylinder bore to allow location of the injector on the opposite side of the centre.

The mean inlet air velocity was computed from the product of the mean piston velocity and the piston area divided by the inlet valve throat area (Giles, 1968). The mean piston speed was computed from:-

Piston Speed (Sp) = 2 x Piston Stroke (L) x Crankshaft Rotational Speed (N) and for the anticipated engine speed of 1800 revolutions per minute (rpm)

$$Sp = \frac{2 \times 0.11 \times 1800}{60}$$

= 6.6 meters per second (m/s)

It has been noted (Heywood, 1988) that resistance to gas flow into the engine or stresses due to inertia of moving parts limit the maximum mean piston speed to within 8 to 14 m/s.

According to Barnes Moss (1975) valve shape proportions and critical design features can be defined in terms of inner seat diameter. The valve head diameter is in turn defined in terms of the cylinder bore.

The following are typical proportions for bowl in piston design.

i) Exhaust valve diameter range is from 0.34 to 0.37 of the bore

ii) Inlet valve diameter range is from 0.43 to 0.44 of the bore.

Poppet valves within the above ranges and subject to local availability were selected. An outside diameter of 38 mm for the inlet port and 34 mm for the outlet were specified. The total length of the valve of 141 mm was found to accommodate all functional features within the cylinder head.

$$\text{Gas velocity} = \text{Mean piston velocity x } \frac{\textit{Piston Area}}{\textit{Valve throat area}}$$

$$= 6.6 \text{ x } \frac{\pi 0.103^2}{4} \text{ x } \frac{4}{\pi \times 0.038^2}$$

= 48.49 m/s

Empirically, the maximum torque for conventional diesel engines has been observed to occur when the inlet gas velocity is about 43 m/s (Giles, 1968). Giles also recommends that the sum of inlet and exhaust valve head diameters not exceed about 85% of the bore. At such values there will be no penalty in the ability to have adequate water cores between the inlet and exhaust ports in the vicinity of the valve seats. The valve stem passes through a renewable valve guide made of cast iron and pressed into the cylinder head.

typical maximum valve lift of 0.25 of the valve diameter was used as a guide. It was noted that the lifts of both the inlet and exhaust valves are normally within the range of 0.2 to 0.3 of the valve diameter (Heywood, 1988).

**Valve seat inserts**

Cast iron cylinder head may have valve seats machined directly in the casing, but it is more common to have them fitted with seat inserts which normally provide for long service life (Leeming and Hartley, 1984).

Valve seat inserts are normally secured through carefully controlled shrinking during which a cold seat is inserted into a heated cylinder head. Typical insert materials are cast iron and alloy steel. The following guidelines were used to install alloy steel inserts.

The size of inserts used were calculated as follows (Automotive Components Limited, 1990):-

i) Outside diameter = valve diameter + 1.7 mm

ii) Inside diameter = port diameter

iii) Depth = deepest possible

These were secured onto the head through interference fits.

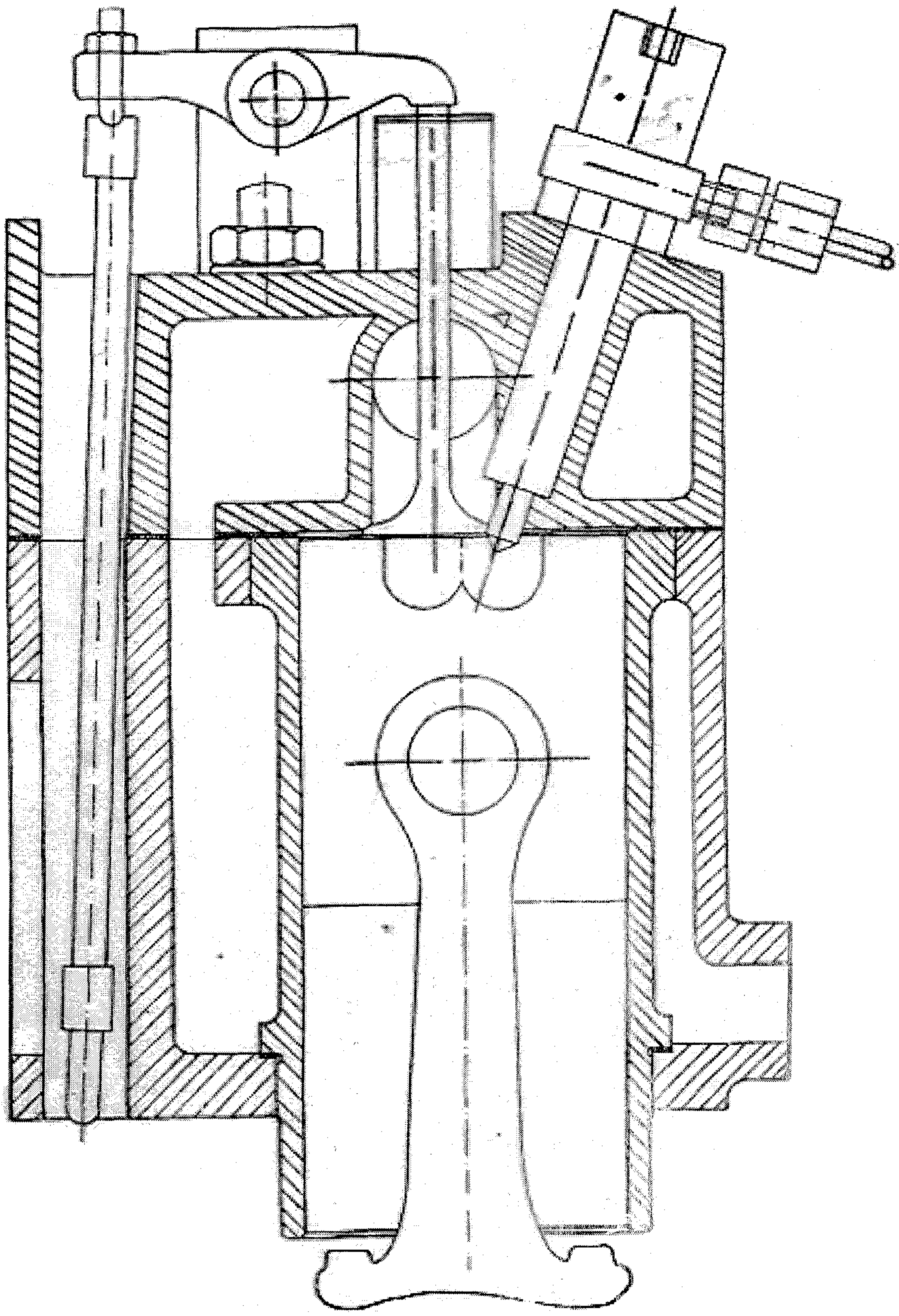

**Figure 1. Main Features of Cylinder Head, Cylinder and piston Assembly.**

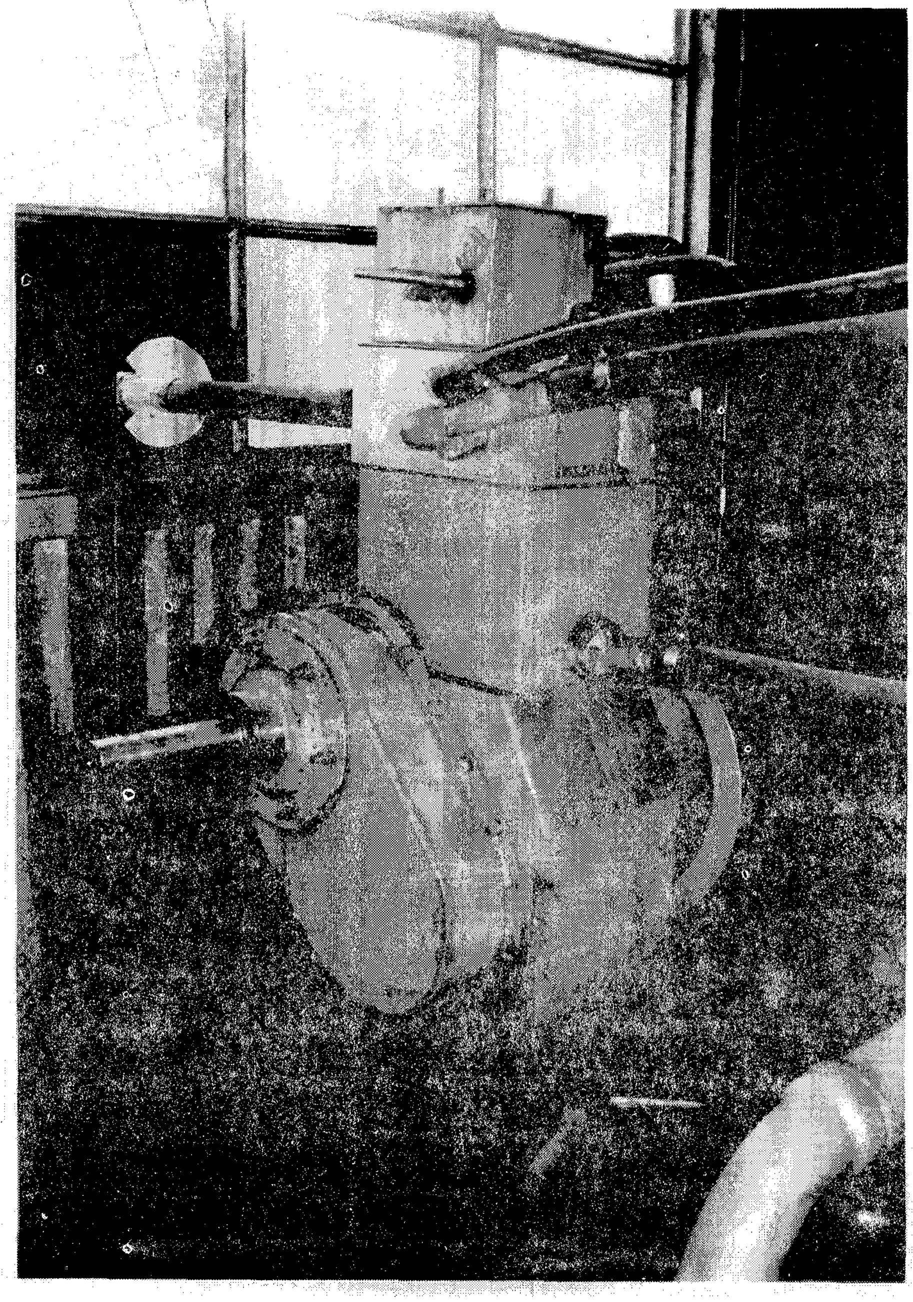

**Figure 2. Completely assembled engine on no load test bench**

COOLING ENGINE SYSTEM

The cooling of stationary engines under consideration is typically based on the principle of thermosyphon circulation. By this system, hot water will tend to rise by virtue of its lighter density, and its place will be taken by cooler water thus causing a definite circulation. The hottest part of an engine is the space around the cylinder head and the hot water rises from this part to the top of an elevated water tank. While cooler water flows from the tank bottom to enter the engine at the water inlet on the lower portion of the cylinder block.

The advantage of thermosyphon cooling lies in its simplicity and automaticity. However it requires relatively larger water spaces. Accordingly, water spaces around the cylinders is often 20 to 40% larger than for pump circulation (Judge, 1972).

The total capacity for the present system has been sized as 6 litres on the basis of the empirical ratio of 1.0 litre of water for every 1.0 kW engine power output (Judge, 1972).

## PRODUCTION PROCESS

### Design and Manufacture of Pattern and Corebox

The design drawings of the cylinder head provided the details used to work out the pattern and corebox dimensions and to incorporate casting shrinkage, draft angles to facilitate withdrawal of the pattern from the mould and to provide allowance for machining.

The pattern was constructed as a single unit without a parting line. However, the internal shape of the cylinder head demanded that the core box be constructed as an assembly of sections. The sections comprised of:

i) Inlet and exhaust port core box.
ii) The water jackets core boxes.

And the material used for the pattern and the core boxes was hard wood. Maintaining the dimensions and shape profiles as designed for the valve locations, the fuel channel, the exhaust and inlet ports, and with a surrounding water jacket proved to be most demanding in the attempt to ensure dimensionally consistent assembly of the core boxes. In addition, the complexity of the cooling channels and the lack of an adaptable machine to shape the profiles necessitated employing the manual skills of a pattern maker. In the absence of guiding templates, uniformity of the sizes and shapes was achieved with difficulty. The core boxes were supported in the moulds so as not to impair the functions of the final product. This was achieved by locating the core prints where they also doubled as the inlet and exit openings for the cooling fluid within the cylinder heads.

### Moulding

The foundry sand selected for moulding of the cylinder head was of the AFS 80 - 110 grade. The selected grade ensured the casting had a good surface finish appearance. The mould was made using clay bonded (bentonite) dry sand moulds. This was dried to limit the defects related to gas evolution from the sand additives and also to increase the mould strength and stabilize it during the core assembly stage. A refractory mould coating was applied on the moulds to enhance the casting surface finish and to reduce the effects of sand burn-on as could occurs on the surface of the castings.

### Core Making and Core Assembly

The materials used for making the cores were selected from inorganic binders employed in the cold box process. This selection was preferred to eliminate gas generating materials from the making of the cores. Since, cylinder head cores are completely enclosed by molten metal, any gas generated from the cores has no escape route and therefore ends up generating internal gas porosities. The $CO_2$/sodium silicate process which incorporates dexil as the brakedown agent was used.

Cores were made manually using the cold box process. This resulted in difficulties in the control of the gassing pressure, the gas flow rate, the gas temperature and the cores made were observed to vary in strength, friability and dimension consistency.

This posed a problem during core assembly and made repeatability of the internal shape details difficult to achieve.

However, after several attempts, the moulders were able to develop acceptable levels of consistency. The assembled cores were coated with a refractory mould coating and oven dried to eliminate gas evolution from moisture during casting. The cores were then assembled and set in the moulds in readiness for pouring of molten metal.

### Melting and Casting

Selected gray iron scrap was melted in a cupola furnace. Adjustments on the composition was made in the ladle which contained the required quantity of molten metal. The metal was tapped from the cupola at a high temperature of about 1500°C to cater for the temperature drop during ladle composition adjustment. Control of the silicon content was necessary to avoid production of white unmachinable castings while addition of manganese was to strengthen the matrix. Traces of chromium and nickel were picked from the scrap.

Casting was at a temperature of 1430°C to allow filling of thin sections found around the cooling channels without suffering from premature freezing. Locations identified as having relatively large cross sections were provided with feeder heads to eliminate solidification shrinkage. Casting gates were provided with adequate cross sections for control of mould filling without introducing turbulence while at same time fast enough not to generate coldshuts.

**Fettling**

Fettling of the castings proved difficult especially in clearing the cores out of the castings. The $CO_2$/silicate process has the inherent property of hardening on application of heat during casting. Though the dexil additive serves as an aid in breaking down the cores, thin sections of the castings surrounded by heavy mass of metal altered the properties and the behaviour of the core material. This made it difficult to extract the cores from the narrow sections of the cooling channels. Complete removal was only possible after prolonged use of steam at high pressure.

### 3.0 CONCLUSION AND DISCUSSIONS

All parts of a cylinder head are subjected to heat flow and the resultant temperature gradients. If the effects are not adequately relieved through the cooling system, distortions are inevitable, and during compression and power strokes leakages would be experienced. The specific locations of areas of high thermal stresses on a conventional head are the areas around the spark plug and injector and especially between them and the valve seats.

The development of the present cylinder head was iterative and involved many hours of trial runs on a test bench. Each prototype was initially tested in the following aspects:

i) A cooling system tester was used to detect leakages due to lack of integrity of the casting.

ii) Appropriate adapters were used to facilitate circulation of the cooling fluid to detect any restrictions on its passage.

iii) A compression tester was used to test for leakages of pressure through valve seats, injector seat, or cylinder head and block surfaces.

The third prototype was found to satisfy the prescribed conditions and was subsequently mounted on the engine for bench trials.

During the bench trials the engine was run at its rated speed of 1800 revolutions per minute for an approximate duration of 100 hours during which the following parameters were continually monitored:-

i) The temperature of the cooling fluid.

ii) The level of compression at intervals, of 10 hours.

These parameters were observed to remain at normal levels throughout the trial period. The design and production of the cylinder head was considered to have demonstrated the local availability of facilities, that with guided know-how could be used to manufacture the most complex component of a single cylinder diesel engine.

This exercise served to emphasize the need to develop the manufacturing of replacement parts for basic equipment used in the local environment.

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