

# Design and Analysis of Cylinder and Cylinder head of 4-stroke SI Engine for weight reduction

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## Abstract

The present paper deals with design of cylinder & cylinder head with air cooling system for 4 strokes 4 cylinder SI engine. The main objective of design is to reduce weight to power ratio & will result in producing high specific power. The authors have proposed preliminary design cylinder & cylinder head of a horizontally opposed SI engine, which develops 120 BHP and posses the maximum rotational speed of 6000rpm. Four stroke opposed engine is inherently well balanced due to opposite location of moving masses and also it provides efficient air cooling.

For the requirement of weight reduction the material selected for design of cylinder and cylinder head is Aluminum alloy that is LM-13. The cylinder bore coating using NIKASIL coating was done to improve strength of cylinder with minimum weight..

## 1.0 Introduction :

### Horizontally opposed four stroke four cylinder si engine:-

A flat-4 or horizontally-opposed-4 is a flat engine with four cylinders arranged horizontally in two banks of two cylinders on each side of a central crankcase. The pistons are usually mounted on the crankshaft such that opposing pistons move back and forth in opposite directions at the same time. The general layout of this engine is shown in fig. 1

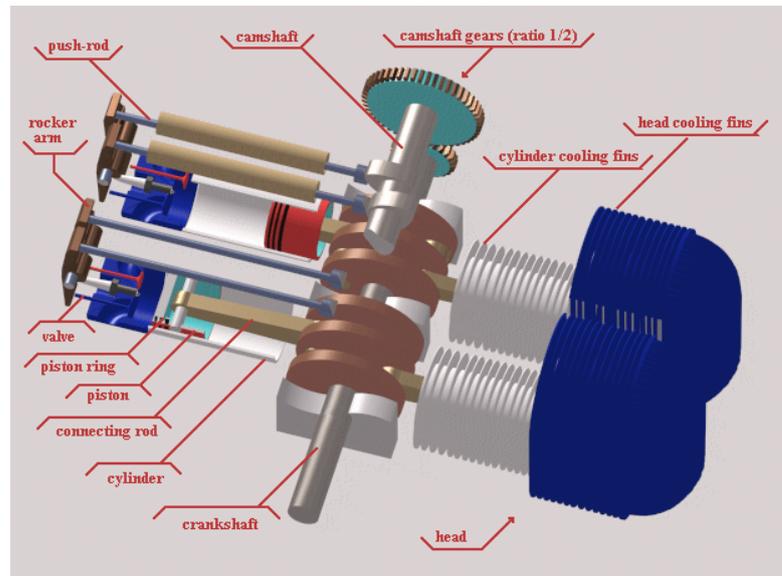


Fig 1. Layout of horizontally opposed 4 cylinders, 4 stroke SI Engine

The configuration results in inherently good balance of the reciprocating parts, a low centre of gravity, and a very short engine length. The layout also lends itself to efficient air cooling. However, it is an expensive

design to manufacture, and somewhat too wide for compact automobile engine compartments, which makes it more suitable for cruising motorcycles and aircraft than ordinary passenger cars.

This is no longer a common configuration, but some brands of automobile use such engines and it is a common configuration for smaller aircraft engines such as made by Continental. Although they are somewhat superior to in-line 4stroke engines in terms of vibrations, they have largely fallen out of favour because they have two cylinder banks thus requiring twice as many camshafts as for in-line engines.

**2.0 Material Selection**

As means for reducing weight, there are several methods available substituting light weight materials for conventional materials, that is to decrease specific gravities, rationalization of structure (decrease the number of parts through integration), & downsizing (decrease the volume of each part).

In the past, the engine performance has been compromised in order to improve emission. The methods presented here, however are fundamentally different from the past one.

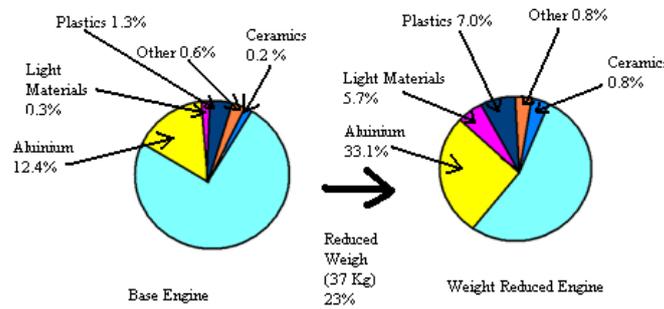


Fig 2. Material Composition of Weight-Reduced Engine & Base Engine [1]

The engine weight has reduced by 37 Kg from a base one of 162 Kg (excluding engine oil). This corresponds to 23% weight reduction. As shown in fig. 2 the component weight ratio of the materials are 53% steel for the weight-reduced engine (86% in the base engine), 33% (13%) Aluminum alloys, 7% (1%) plastics & elastomers, 6% (0%) other light weight materials such as titanium alloys & magnesium alloy, & 1% (0%) ceramics.

The materials substitutions applied for the engine structure component represented by a cylinder is no more than simple weight reduction. But, when applied this to several moving & functional components, it not only weight reduction method but also contributes to improve engines & emission performance.

## 2.1. Material Comparison <sup>[1,4]</sup>

Table 1 .0 Material Comparison.

PARAMETER	LM12	LM13	LM14
<b>Chemical composition (%)</b>			
Si	2	11/13	0.6
Fe	0.5/1.5	0.8	0.6
Cu	9/10.5	0.5/1.3	3.5/4.5
Mg	0.15/0.35	0.8/1.5	1.2/1.7
Ni	0.5	0.7/2.5	1.8/2.3
Mn	0.6	0.5	0.6
Pb	0.1	0.1	0.05
<b>Mechanical properties</b>			
$\sigma_u$ (N/mm <sup>2</sup> )	220 to 268	173 to 252	220 to 283
Brinell Hardness Number (BHN)	100	100	100
<b>Characteristics</b>	1) Good hardness at elevated temperature 2) Good strength 3) Good resistance to wear	1) Good fluidity 2) High temperature strength 3) Low coefficient of thermal expansion 4) Good resistant to wear & low weight.	1) Excellent strength 2) Excellent hardness at elevated temperature

From above it is clear that, the material suitable for given application is LM-13. Because it has a low thermal coefficient also for further processing of coating on cylinder bore of this material is well suited.

## 2.2 Cylinder Bore Coating

The important parameters for light weight & high speed engine application are the selection of the material & the surface modification by hard coating on bore of cylinder block.

The strength to weight ratio has also become an important parameter for the design consideration as it has multiple advantages e.g. improved fuel efficiency, load carrying capacity etc. For the development of light weight cylinder block for air borne application, the use of cast iron liner has been replaced by hard coating technology on the cylinder wall surface. In INDIA the hard layer coating technology on Aluminum is found in application.

Following kinds of hard layer surface coating over Aluminum has been successfully achieved in foreign countries.

- Nikasil (Ni + SiC composite coating)
- Hard chrome coating.
- Apticoat 750 (Ni + Ceramic composite) developed by M/s SAT Poeton Ltd., UK for racing car.

### a) Nikasil Coating <sup>[9]</sup>:-

It is basically an electrochemical dispersion coating on the cylinder bore where the Silicon Carbide particles (SiC) are dispersed in the Nickel matrix. It is generally desired to deposit the coating as free as possible to tensile stress. In this case NIKASIL exhibits a very favorable behavior where the stress do not exceeds 120 N/mm<sup>2</sup>. The Nickel matrix is characterized by hardness up to 550 VPN as well as certain amount of ductility. The reinforced Silicon Carbide particles, which can be identified in Nickel matrix as dark dots under microscope having hardness approximate 2500 VPN. The size of particle is restricted to 4 micron as the coarser particles are not favorable in wear condition with the mating parts (piston ring). The uniform dispersion of Silicon Carbide particles in the Nickel matrix mainly depends on the ratio of mixture of nickel & Silicon Carbide & also the current density. NIKASIL coated cylinder blocks have a better engine performance over the cast iron blocks or Aluminum blocks with cast iron liner.

TABLE 2. Improvement of engine performance by cylinder block material <sup>[9]</sup>

Material	Sfc (gm/kw-hr)	Thermal conductivity (W/mk)	Weight (kg)
Cast iron	490	54	2.18
Aluminum barrel With cast iron sleeve	380	54-109	1.12
Aluminum barrel with NIKASIL plating	310	109	0.78

**b) Hard Chrome Plating <sup>[9]</sup>:-**

The hard chrome plating on cylinder block of Aluminum alloy is done through electroplating deposition. In this process cylinder blocks are made cathode & the anode, usually made of lead (Pb), acid solution. The dimension of the anode depends on the bore diameter & stroke length of cylinder block. The thickness of coating is controlled by knowing the total surface area of the cylinder bore & adjusting the current density. It has been reported that a coating thickness of 60-70 microns on bore surface of Aluminum cylinder block gives better fuel efficiency & thermal conductivity in comparison with Cast Iron cylinder blocks or Aluminum barrel fitted with Cast Iron liner.

**Selected Coating:-**

**NIKASIL** coating is selected for coating of cylinder bore because it has got better performance compared to hard chrome plating. Also NIKASIL coating has got hardness about 2500 VPN where as chrome plating has only 800-900 VPN.

**3.0 Basic Engine Design**

**3.1- Design of Cylinder:**

Table 3. Cylinder Dimensions

Design parameters	Calculated value
D	78mm
L	78mm
Bmep	11.76 bar
Imep	13.85 bar
Pmax	138.5 bar
Volume	1500cc
Indicatedpower	141.176 HP
Friction Power	21.176 HP
Mechanical Efficiency(assumed)	85%
Break power	120 HP

**3.2 Cylinder Thickness Design**

Thickness of Cylinder is 5 mm.

**3.3 Cylinder Head Design:**

Table 4.0 Cylinder Head Dimensions.

Deign Parameter	Calculated values
Cylinder wall thickness t	5 mm
Cylinder head thickness t'	9 mm

**3.4 Valve Spacing On Cylinder Head:-**

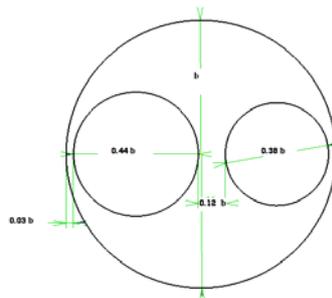


Fig 3. Valve spacing diagram <sup>[2]</sup>

Figure shows the empirical relation for inlet & exhaust valve spacing.

Clearance between valve & bore = 2.3 mm

Space between valves (inlet & exhaust) = 9.36 mm

**3.5 Inlet And Exhaust Manifold Design:-**

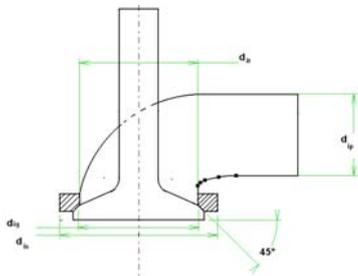


Fig. 4. Inlet Manifold .

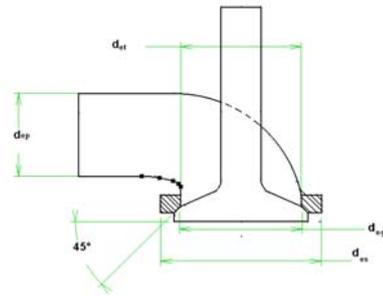


Fig. 5. Exhaust Manifold .

**3.6 Valve Seat:**

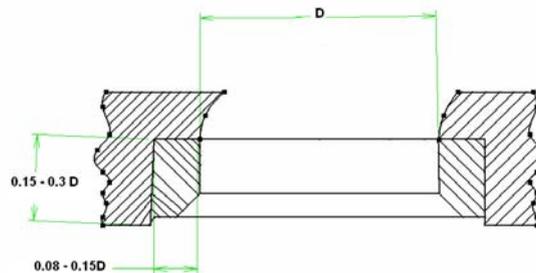


Fig 6. Valve Seat design [6]

From figure we get the relation for valve seat outside diameter & height.

**3.7.1 Inlet Valve Seat Design:-**

Thickness of valve seat (t)<sub>i</sub> = 3.517 mm

Height of valve seat (h)<sub>i</sub> = 9.0558 mm

**3.7.2 Exhaust Valve Seat Design:-**

Diameter of valve seat (D)<sub>e</sub>:- 24.57 mm

Thickness of valve seat (t)<sub>e</sub> = 3.003 mm

Height of valve seat (h)<sub>e</sub> = 7.37 mm

Table 5. Dimensions of valve seats:-

PARAMETER (mm)	INLET VALVE SEAT	EXHAUST VALVE SEAT
D	30.186	24.57
t	3.517	3.003
h	9.0558	7.37

**3.8 Design Of Cooling Fins**

**Material:** - Aluminum alloy (Thermal conductivity =109 web/mK)

Table 6 Dimensions of cooling fins

Required parameter	Calculated value
Root thickness of the fin,	3 mm
Space between two fins	3.96 mm
Number Of fins	24
length of fin	25 mm

#### 4.0 Solid modeling of Cylinder

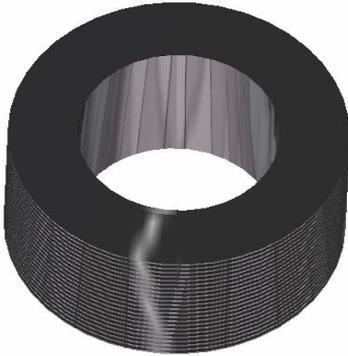


Fig . 7. Model of cylinder

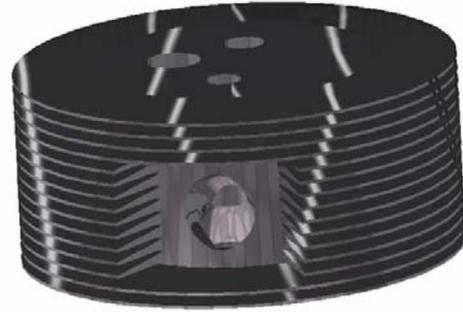


Fig. 8. Model of cylinder head

#### 5.0 FEA ANALYSIS OF Cylinder And Cylinder Head

Table 7 Input parameters for analysis

PARAMETER	VALUE
Maximum pressure	1.38e+007 N/m <sup>2</sup>
Maximum temperature	1032 K
Young's modulus	7e+010 N/m <sup>2</sup>
Poissons ratio	0.34
Density	2700 Kg/m <sup>3</sup>
Thermal expansion	2.968 e-004 (1/K)
Yield strength	346e+008 N/m <sup>2</sup>

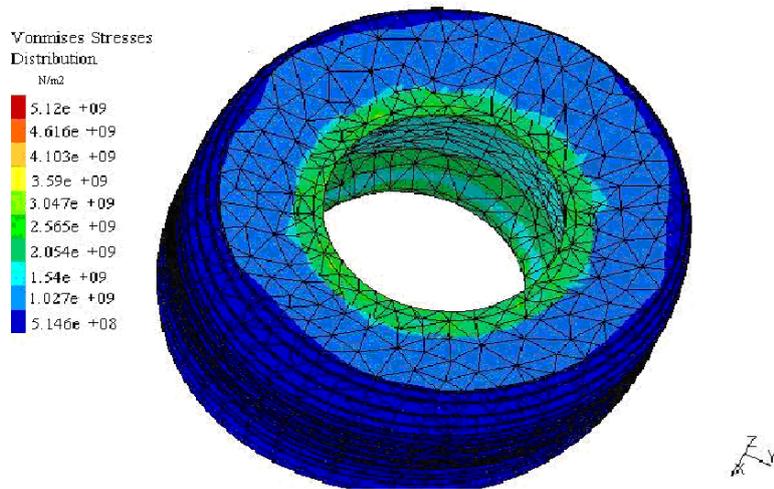


Fig. 9 Analysis of cylinder

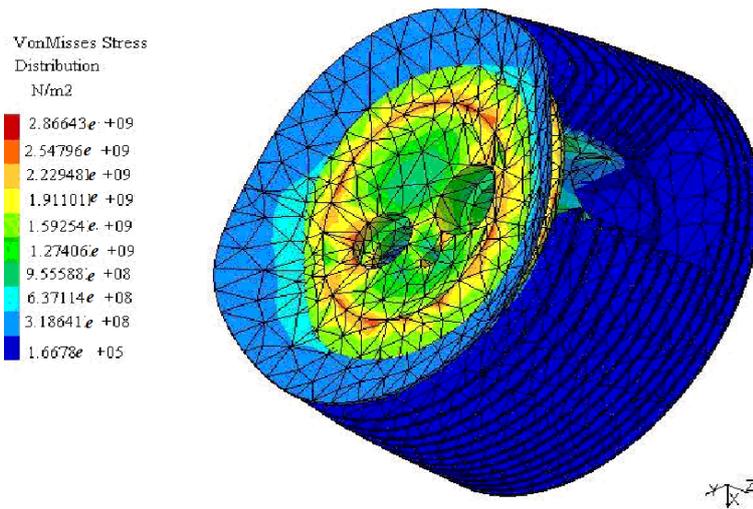


Fig. 10 Analysis of cylinder head

## 6.0 Conclusion

From the analytical solution & the analysis result we get the values of stresses produced in cylinder and cylinder head due to application of temperature and pressure are within permissible limit. Hence we concluded that the basic design of cylinder and cylinder head is safe with reference of pressure and temperature basis. Due to the use of light weight material i.e. LM-13 with NIKASIL cylinder bore coating, we can effectively reduce the weight of cylinder and cylinder head with improved strength. Also due to the use of air cooling system an efficient and faster cooling of engine achieved.

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