Design of Cylinder Head Gasket

Abstract

The gas and liquid escaping from the engine due to leakage not only affects the performance of the engine but also pollutes the environment and increases the risk of unexpected accidents. To improve the effectiveness of the gasket sealing, it is important to consider the pre-stressing force of the bolts and the gasket design. Therefore, by applying the appropriate investigative procedures and tests, it becomes important to ensure that the assembly of the cylinder head, bolts, and gasket is both reliable and efficient to achieve the goals of the engine being developed. Before conducting a structural and thermal study of the cylinder head gasket, it is essential to assemble the cylinder head, bolts, and gasket properly, considering the pre-stressing of bolts. The various investigators did not consider the thermal stresses produced on the cylinder head due to temperature distribution in the cylinder head area, and their results reveal that the initial stressing of bolts affects the effectiveness of the cylinder head gasket's sealing.

To evaluate the efficiency of cylinder head gaskets and their stress and strain behavior under different loading conditions, the appropriate design of cylinder head gaskets based on contact theory is required. This chapter provides information about the material selection of cylinder head gaskets with different gasket types and gasket joint calculations to determine loss of preload due to gasket seating, loss of preload due to complete connection, available preload after assembly, maximum permissible tightening torque, torsional stress generated in the smallest cross-sectional area of the bolt, cylinder head fixation required preload for each bolt, and tensile stresses generated in the bolt.

Key words: Pre-stressing force on bolt, Cylinder head gasket, Gasket joint calculations

I. Introduction

A gasket is a mechanical assembly's means of establishing and maintaining a barrier against the passage of liquids and gases between mating surfaces. The cylinder head gasket is used to seal the cylinder head and block of a gasoline or diesel engine. It is an essential component of the engine and has to perform multiple tasks simultaneously when the engine is running. The seal around the combustion chamber, coolants, engine oil, and air must be maintained at the optimum operating pressure and temperature by the cylinder head gasket. The materials used in the gasket's construction and its design must be chemically and thermally resistant to combustion byproducts as well as to the various chemicals, coolants, and oils employed in the engine. The cylinder head gasket becomes an important part of the engine's overall structure when the engine block, cylinder head, and gasket are all assembled, as shown in the figure. 1. It holds up the cylinder head and all of its functional parts. It must be capable of withstanding the heat and dynamic forces transferred from the head and block. The cylinder head gasket design will be based on the type of engine used.

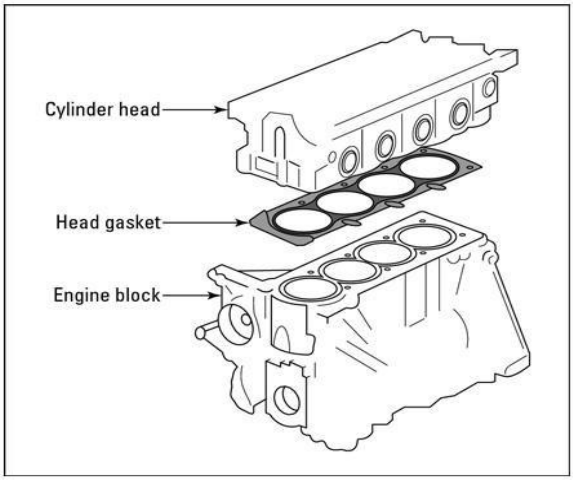

Figure 1: Assembly of Cylinder, Cylinder head and Gasket

A cylinder head gasket failure could occur if the engine overheats and operates beyond its normal operating range. The high temperatures may cause an excessive amount of stress on the cylinder head. This happens if aluminum cylinder heads are used, because after heating aluminum expands more than cast iron, which could result in a loss of pre-stressing in crucial locations and cause the head gasket to leak.

II. Theoretical background

A. The Contact Theory

In contact theory, it is assumed that the cylinder head, bolts, and gasket are not perfectly flat at some scale. The cylinder head gasket initially goes through a plastic deformation process to support the entire contact force. The contact pressure has a direct proportional relationship with the size of the plastically deformed gasket zone, while the hardness of the material has an inverse relationship.

B. Thermal Stress

A cylinder head gasket under mechanical stress responds to temperature variations by expanding or contracting. Thermal stresses are those kinds of stresses caused by a change in temperature. It is necessary to do a heat transfer analysis of the cylinder head before performing the structural analysis. The heat condition equation in the material can be expressed as follows in accordance with the energy conservation principle:

$$\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2} = 0$$

With proper boundary conditions, it is possible to detect the temperature distribution in the material. The strain components of the element, including the thermal strains, are provided below according to generalized Hooke's law.

$\epsilon_X=(\sigma_X - \mu(\sigma_y + \sigma_Z))/E + \alpha\,\Delta T$

$\epsilon_y = (\sigma_y - \mu(\sigma_Z + \sigma_X))/E + \alpha\,\Delta T$

$\epsilon_Z = (\sigma_Z - \mu(\sigma_X + \sigma_y))/E + \alpha\,\Delta T$

$\gamma_{xy} = \tau_{xy}/G$

$\gamma_{yz} = \tau_{yz}/G$

$\gamma_{zx} = \tau_{zx}/G$

Where,
T = temperature,
ε = Normal strain,
σ = Normal stress,
ν = Poisson's ratio,
E = Young's modulus of elasticity,
ΔT = Incremental temperature,
α = Coefficient of thermal expansion,
τ = Shear stress, and **γ** is the shear strain.
G = Shear modulus,

III. Gasket Design

In order to fulfill the specific performance requirements of the engine, each application needs a unique cylinder head gasket design.

A. Selection of gasket material

The materials and designs implemented for the cylinder head gasket are the outcome of evaluating various engineering metals, composites, and chemicals for use in a gasket in order to maintain the requisite sealing capabilities throughout the duration of the engine. The physical characteristics of the material are significant elements for determining the gasket design, and the major selection of a gasket material is based on the temperature and pressure of the fluid to be contained, the degree of corrosivity, and the criticality of the application.

Important material properties for the selection of a gasket –

- Compatibility: to withstand the sealing of the media being contained.
- Heat resistance: to Withstand the environment's ambient temperature.
- Compressibility: conforms to the irregularities and curves of the mating surfaces of the fanges.
- Micro-conformability: to flow through the surface irregularities of the mating flanges
- Recovery: to adhere to the motions produced by thermal and mechanical forces.
- Creep relaxation: to sustain sufficient stress for continuous sealing over a lengthy period of time.
- Compressive strength: to withstand crushing and/or extrusion brought on by high stresses.
- Erosion resistance: to allow fluid impact in situations where the gasket has to act as a measuring device.
- Tensile strength: to withstand rupture caused by pressurized media.
- Autistics: to ensure gasket removal without sticking.
- Shear strength: to manage the shearing motion of the joining flanges caused by the mechanical and thermal effects of the joining flanges.
- Heat conductivity: to Permit the heat transfer of the application.
- Acoustic isolation: to provide necessary noise isolation for the application.

1. Non-metallic gaskets-

- Non-metallic materials are generally used when the gasket material easily compresses with a light bolt load and has dimensional stability.
- These gaskets are prepared from cork, rubber, plastic, and asbestos material.
- Asbestos gaskets have sharp edges; hence, they provide admirable resistance to crushing loads and cutting action.

- Rubber parts are extremely impermeable and can flow into joint flaws when compressed.
- They are available in the form of compressed fiber sheets, PTFE, graphite and thermo lite, insulating gaskets.
- They are inexpensive but susceptible to fungi and alkalis.
- The Limit temperature for asbestos gasket is 250 and other non-metallic gaskets are 70
- Application: low to medium pressure services, extreme chemical services, and temperatures such as heat exchangers, compressors, bonnet valves, and applications involving uneven surfaces.

2. Semi-metallic gasket-

- These composite gaskets are made of metallic and non-metallic materials.
- The gasket's strength and durability come from the metal, while its conformable sealing substance comes from the non-metallic component.
- When compared to full metallic gaskets, semi-metallic gaskets are designed to have soft, malleable sealing materials, which improve the assembly's tightness with lower overall load requirements. Because of this structure, they are the most widely used and are available in a huge range of styles and sizes.
- Typically, they can be fabricated from any metal that is accessible in thin strips or sheets and can be welded. They can therefore be employed over almost any corrosive medium, depending on the metal and filler or facing material that is used.
- They are applicable across the entire temperature range, from cryogenic to around 2000 °F (1093 °C).
- Semi-metallic gaskets such as spiral wound gaskets, metal-jacketed gaskets, and metal-reinforced gaskets are available.
- Application: low and high pressure and temperature applications

3. Metallic gasket-

- Lead, copper, or aluminum sheets are the main components of a metallic gasket. When these gaskets are compressed during assembly, they are permanently set, and there is no recovery to consider contact face separation. Additionally, they are vulnerable to corrosion and chemical conditions, and the surface finish of the interacting surfaces affects how well they work.
- The maximum operating temperatures for metallic gaskets are shown in Table No. 1.

Table 1: The maximum operating temperatures for metallic gaskets

Sr.no	Gasket material	Maximum operating temperature ^{0}C
1	lead	90
2	copper/brass	250
3	Aluminum	400

- Metallic gaskets can be found as lens rings, weld rings, ring-type joints, and solid metal gaskets.
- Application: high-pressure and high-temperature applications

The most frequently used gasket materials are as follows:

1. Fiber-based composite materials
   There are three types of fiber composite materials used
   a) Carbon Fiber
   b) Pyrosic glass ceramic
   c) Kevlar fiber

Table 2: The mechanical properties of carbon Fiber, Pyrosic glass ceramic, Kevlar fiber

Sr.no	Property	Carbon Fiber	Pyrosic glass ceramic	Kevlar fiber
1	Modulus of Elasticity (Gpa)	70	43	95
2	Ultimate Tensile Strength (Mpa)	600	350	1300
3	Ultimate Compressive Strength (Mpa)	150	95	280
4	Poisson's ratio	0.1	0.1	0.34
5	Thermal conductivity (W/mk)	0.90	0.95	30
6	Density (g/cm$^{3)}$	1.78	1.8-2.2	1404

1. Composite material Properties

- High strength at elevated temperatures
- Toughness (thermal shock resistance and impact)
- Improved oxidation and corrosion resistance
- Conductivity and controlled thermal expansion
- Greater hardness and erosion resistance

2. Graphite materials: Graphite materials are generally used for the outer layer of the gasket.

- Graphite is excellent at handling high temperatures, and it is anisotropic.
- It can be crushed and extruded if used in oil over a long period of time.
- Leaves a covering on the block and head that is challenging to remove.

3. Stainless steel and steel of various grades and forms

- Steel and stainless steel do not easily corrode.
- It is not completely stain-resistant.

Table 3: Mechanical properties of Stainless steel

Sr.no	Property	Value
1	Modulus of Elasticity (Gpa)	190
2	Ultimate tensile strength (Mpa)	400
3	Ultimate compressive strength (Mpa)	570
4	Poisson's ratio	0.2
5	Thermal conductivity (W/mk)	16.3
6	Density (Mg/m$^{3)}$	7.85

B. Selection of Cylinder Gasket type -

1. Sandwich Gasket-

The sandwich-type gasket is shown in Figure 2. This gasket is constructed using copper or steel plate on the outer surfaces and asbestos millboard in the center. The grommets, or eyelets, are incorporated into these gaskets.

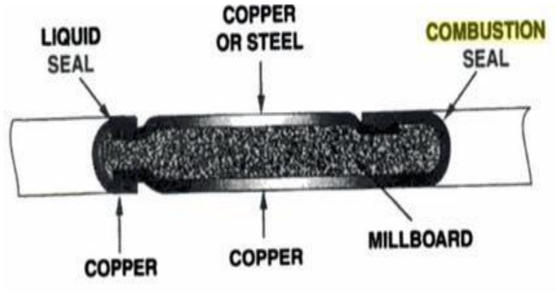

Figure 2: Sandwich gasket

2. Strengthened Sandwich gasket

The strengthened sandwich gasket is shown in Figure 3. For better sealing, these designs employ a variety of reinforcements at the combustion chamber seal. In many constructions, metal shims and strengthened filler materials are used.

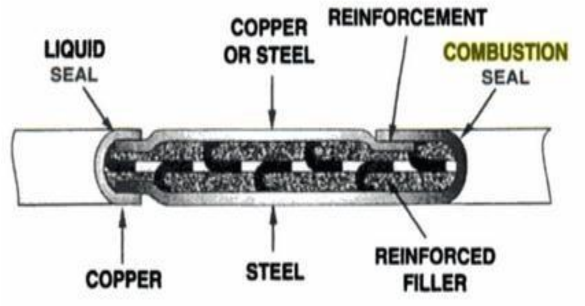

Figure 3: Strengthened sandwich gasket

3. Embossed steel shim

An embossed steel shim gasket is shown in Figure 4. A plastic resin covering has been added to the all-metal embossed steel shim gasket for micro-sealing purposes. This gasket naturally has good torque retention. However, as engine displacement increased, the elastic response of the illuminated design was unable to accommodate it. Furthermore, the land gaps, especially those between cylinders, were commonly made smaller to the point where the embossed legs would cover up ports, making efficient sealing difficult.

Figure 4: Embossed steel shim

4. Perforated-core head gasket

These designs have a perforated steel sheet as the core, and the facing materials are mechanically attached to either side of the core. This works without retorquing the cylinder head bolts, and soft sealing material surfaces are given for water and oil sealing.

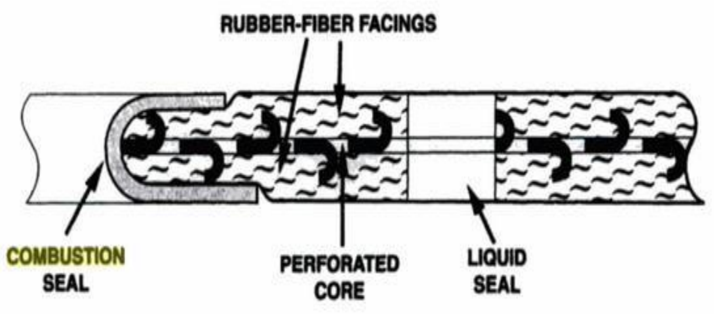

Figure 5 : Perforated-core head gasket

5. Unbroken-metal-core head gasket

The unbroken-metal-core head gasket is shown in Figure 6. In this design, instead of a perforated core, an unbroken steel core is used with a rubber-fiber facing, to which an adhesive is applied to bind the facing. Many of the more difficult sealing applications now use this layered gasket. To create greater sealing stress in specific passageways, the gasket body might be embossed. Elastomeric beads are produced at critical passageways using silk screening, which is another method for sealing them.

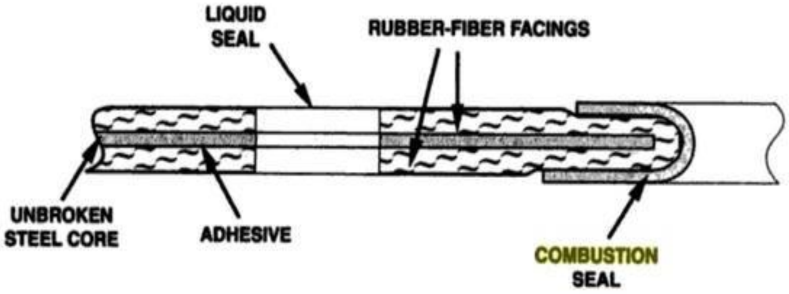

Figure 6: Unbroken-metal-core Head Gasket

6. Multilayer steel head gasket

The multilayer steel head gasket is shown in Figure 7. A rubber coating is applied to many layers of spring-tempered stainless steel that have been embossed. A little change can be seen in these gaskets as the engine runs. High elastic recoveries are obtained when spring-tempered stainless steel is used for embossing layers.

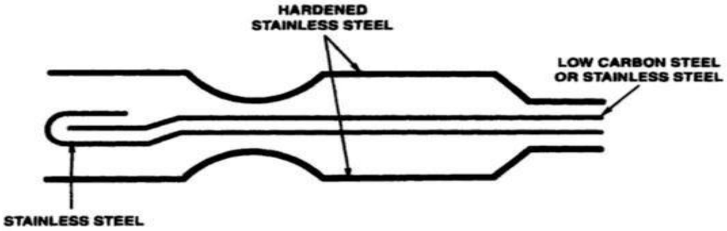

Figure 7: Multilayer-steel head gasket

7. Head gaskets for combustion sealing

1. Stainless steel armor with a steel ring head gasket

The stainless steel armor with a steel ring head gasket is shown in Figure 8. Diesel engines frequently use a low-carbon steel ring, which offers a high unit sealing stress at a very low loading. Typically, using stainless steel armor wrapping, the wire is butt-welded to the gasket body. In certain situations, the wrapping might be tabbed to increase the loading on the wire ring while decreasing the force needed to embed the armor into the body.

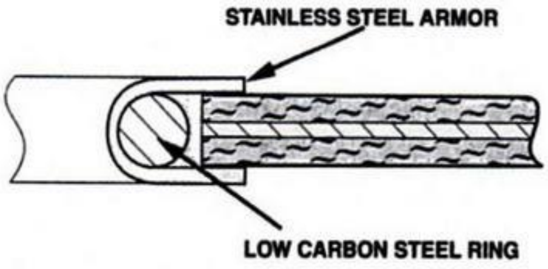

Figure 8 : Stainless steel armor with a steel ring head gasket

2. Armored embossed metal

The armored, embossed metal gasket is shown in Figure 9. This is utilized in many engines to seal up the combustion area. A wide range of load compression qualities can be achieved by varying the height and width of emboss. Since the core of the gasket and emboss are produced from the same piece of metal. When embossing is made from the core of the gasket body, variations in thickness tolerance are minimized. Stainless steel, or low-carbon steel, is used for armor.

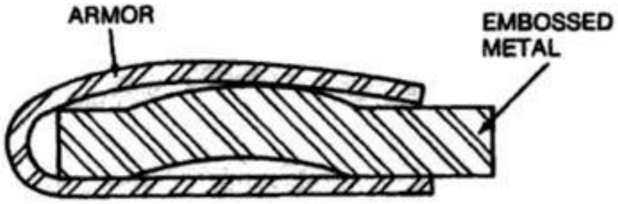

Figure 9 : Armored embossed metal

C. Design strategies for combustion sealing

There are two basic design strategies for combustion sealing. The first combustion sealing strategy known as "massif" refers to the employment of a thick steel gasket blank, or "core" that can be developed either during gasket fabrication or by application of the clamping force during engine building. The second combustion sealing strategy, known as "multi-layer steel," makes use of several layers of formed steel and coatings. 'Functional layers' refers to the developed steel layers of the several-layer steel gasket (SLS). The forming process of these layers is called embossing, and the final component prepared is called embossment. There are two different SLS gaskets available for combustion sealing. Obstacle type and no-obstacle type

1. Obstacle type-

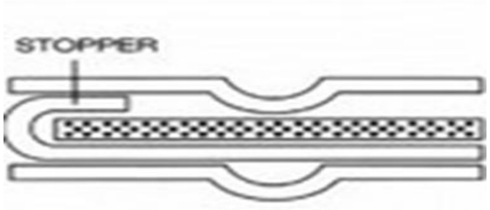

Figure 10: Obstacle-type gasket

The obstacle-type gasket is shown in Figure 10. Include a sheet with a uniform but variable thickness called the stopper or obstacle layer. It can be placed between two functional layers, directly against the cylinder head or block, or between two functional layers and their distance layer. Obstacle layers are used to prevent functional layers from being completely compressed.

2. No obstacle-type

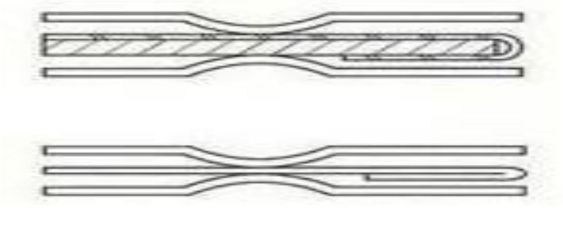

Figure 11: No obstacle-type gasket

A no obstacle-type gasket is shown in Figure 11. It is made up only of an operational layer and an additional layer, or a backup layer. High-temper stainless steel is used to fabricate the functional layers of the SLS gasket, and specially designed embossments are used to give the sealing joint high unit loading and good dynamic recovery. The backup or additional layers are made from carbon steel or stainless steel, which provide a proper compressed thickness and load balancing between the functional layers. The SLS gasket creates a strong, longlasting micro seal inside the sealing. Current coating materials include nitrite butadiene rubber, fluoropolymer, and molybdenum graphite. Coating materials are always being refined to increase salability.

Properties of SLS gaskets

- High durability
- Using lower bolt forces to seal
- High chemical and heat resistance
- More precise control of the installed compacted thickness
- Greater bolt retention forces over the course of operation
- Improve the stability of joints after installation
- High bolted joint's dynamic responsiveness level
- Provide the sealing joint with high unit loading and strong dynamic recovery
- Lower total weight
- Reduce rigidity

Construction of SLS gaskets

The SLS cylinder head gasket is made from several steel layers that collectively make up the gasket's body. The gasket's body material is often made of low-strength steel, which serves only to support the gasket. Graphite and composites are two more materials that are commonly used. There are several unique regions inside the layers, all of which are important to the sealing process. The top and bottom sheets, which represent the gasket's active layers, are constructed from beads. The beads transform bolt forces into sealing forces and are responsible for providing excellent sealing. The stopper/obstacle area refers to the bead material that covers the cylinder opening. The section, which acts as the first line of sealing against leakage, has to be the most substantial and stiffest in order to provide sufficient sealing pressure against the combustion gases. Typically, the stopper (also known as the fire ring) is distinct and stiffer than the rest of the gasket. According to research, the stopper area bears between 60 and 80 percent of the stress caused by bolt loading. Therefore, load distribution, head liftoff, bore distortion, and fretting are significantly influenced by the stopper region. The second sealing line, which is made up of beads in the working layers, is situated behind the stopper region. The body's active layers offer sealing for the coolant and oil circuits. Coatings are commonly applied to the gasket's layers; sometimes the top and bottom surfaces are simply coated. The coating affects the shear behavior of the surfaces and serves as an additional barrier against gas and fluid leaks. Beads come in two varieties: full beads and half beads. Both have different geometries and different functions, as shown in Figures 12(A) and 12(B).

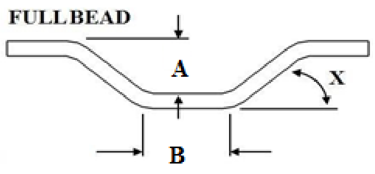

Figure 12 (A): Full bead

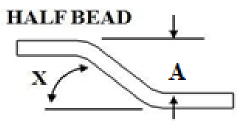

Figure 12 (B): Half bead

The lengths A and B, as well as the angle X, are used to create the beads' particular geometry. During the installation of the head gasket, the full beads are compressed until they reach the stopper's height or until their resistance is equivalent to the tightening force of the bolt. A full bead generates a significant amount of sealing force, and that is needed to completely seal the combustion area. The main purpose is to smooth out the oscillations of the constantly changing sealing gap between the cylinder head and cylinder block at maximum ignition pressures. Half beads are utilized for sealing both coolant and oil in locations far from the cylinder, such as bolt holes, and on outside surfaces. The sealing force of full beads is greater than that of half beads, and they also maintain the necessary sealing force in the combustion chamber area. The steel layer quality, geometry of the bead, sheet thickness, and production process of the bead are the influencing factors for bead stiffness.

The design of a cylinder head gasket is challenging since the gasket must fulfill a variety of functions while having a sufficient usable life. The overall strength of the gasket and its capacity to seal must therefore be balanced. Engine geometry is the main factor influencing gasket design, but other factors also matter, such as combustion temperatures, fluid chemistries, squeezed gasket size, maximum cylinder stresses, deck surface characteristics, bolt tightening force, etc. Geometric beads or embossments are used to create the sealing properties of the gasket. The designer constructs a plane image of the combustion area and every kind of fluid channel to determine the proper design for the sealing beads. Stamping the thin metallic layer between two tool halves produces the beads of each layer and causes residual tensions in the layers. The separate layers are then placed to achieve the requisite compression thickness between the engine block and head as well as the desired spring stiffness characteristics. As shown in Figure 13(A) for engine assembly and in Figure 13(B) for gasket assembly. When the gasket layer beads are combined, they become a single, larger spring from their original state of being small and single. The spring's properties are affected by the material, thickness, hardness, and shape of the layer used for the gasket. There are two types of arrangements for the beads in the subsequent layers: series and parallel, as shown in Figure 14(A) and Figure 14(B).

There are numerous bead configurations in use, making it challenging for the gasket manufacturing sector to match the static and dynamic requirements of engine assembly. The entire gasket must withstand the effects of fatigue throughout its full life and provide appropriate sealing at the highest, lowest, and intermittent loads. The major goal of a gasket designer is to optimize the gasket contact stresses and reduce dynamic head motion because any deterioration of sealing ability would lead to decreased engine performance and even failure.

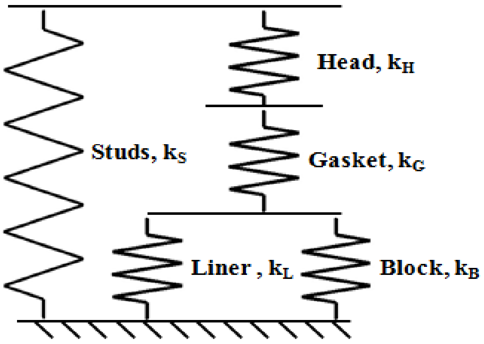

Figure 13(A): Engine assembly

Figure 13(B):Gasket assembly

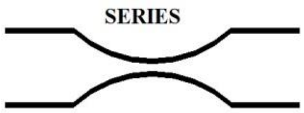

Figure1 4 (A) : Series

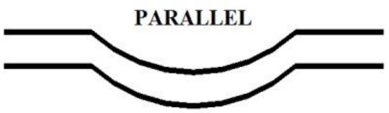

Figure 1 4 (B) : Parallel

D. Gasket joint calculations

1. Stiffness of cylinder head (K_h) is calculated by,

$$K_h = E_h \text{ x } \frac{\mathrm{Area}_{\mathrm{Eq}}}{L_h} \text{ (N/mm)}$$

Where,

E_h = Young’s modulus of elasticity of cylinder head
Area $_{Eq}$ = Equivalent area of cylinder head
L_h = Effective height of head

2. Stiffness of bolt (Kb) is calculated by,

$$(Kb) = \frac{E_b}{\frac{L1}{A1}+\frac{L2}{A2}+\frac{L3}{A3}} \text{ (N/mm)}$$

Where,

L_1, A_1= Length and Area of head to shank of bolt respectively

L_2, A_2 = Length and Area of shank of bolt respectively
L_3, A_3= Length and Area of full thread of bolt respectively

3. Stiffness of gasket (K_g),

$$K_g = E_g \text{ x } \frac{\mathrm{Area}_{\mathrm{Eq}}}{L_g}$$

Where,
E_g = Young's modulus of elasticity of gasket material
Lg = Height of gasket
Area $_{\mathrm{Eq}}$ = Equivalent area of gasket

4. Combined stiffness (Kc)-

When there is bolted assembly of cylinder block, cylinder head and gasket They act as three compression springs, which are in series hence their combined stiffness is calculated by,

$$\frac{1}{K_c} = \frac{1}{K_h} + \frac{1}{K_{bl}} + \frac{1}{K_g}$$

Where,
K_c=Combined stiffness
K_h = Stiffness of cylinder head
K_{bl} = Stiffness of cylinder block
K_g = Stiffness of gasket

5. Loss of preload due to gasket seating only (Fg) is calculated as,

$$F_g = \frac{0.1}{\frac{1}{K_b} + \frac{1}{K_h}} \text{ (N)}$$

6. Loss of preload due to complete connection (Fs) = 1.3×Fg (N)

7. Maximum combustion force (Fc),

$$Fc = \frac{\pi}{4} \text{x} D^2 \text{x} P_{\mathrm{Peak}} \text{ (N)}$$

Where,
D= Bore diameter of cylinder head
P_{peak}= Cylinder peak pressure

8. Available preload after assembly ($F_{Avail.}$),

$$F_{\mathrm{Avail\,.}} = \frac{A_{\min} \times S_{yt}}{\sqrt{1 + 3 \times (\frac{\sigma to}{\sigma t})^2}} \text{ (N)}$$

Where,
A_{min} = Area of minimum C/S of bolt= $\frac{\pi}{4} \text{x} D_{\min}{}^2$
$D_{\min}$ = Diameter of minimum C/S of bolt =D-1.226 x P
P = Lead of head of thread
S_{yt} = Yield strength of bolt
Σto = Torsional tension produced in smallest C/S area of bolt
σt = Tensile stress

$$\frac{\sigma to}{\sigma t} = 2 \times \frac{D_p}{D_{\min}} \times (\frac{P}{\pi \times D_p} + 1.155 \times \mu)$$

Where,
D_p =Pitch diameter of thread
μ = Friction coefficient

9. Maximum permissible tightening torque (T_{per}),

$$T_{\mathrm{per}} = F_{\mathrm{Avail}} \text{ x } \{\frac{D_p}{2} \times \left(\frac{P}{\pi \times D_p} + 1.155 \times \mu\right) + \frac{D_m}{2} \times \mu\} \text{ (Nmm)}$$

Where,
D_m = Mean diameter of bolt head

10. Torsional tension produced in smallest C/S area of bolt (σto),

$$\sigma to = \frac{FAvail \times \frac{Dp}{2} \times \left(\frac{P}{\pi \times D_p} + 1.155 \times \mu\right)}{\pi \times \left(\frac{D_{min}}{16}\right)^3} \ (N/mm^2)$$

11. Tensile stress (σt),

$$\sigma t = \sqrt{S_{yt}{}^2 + 3 \times \sigma to^2} \ (N/mm^2)$$

12. Bolt force at yield strength (F_{Syt}),

$$F_{Syt} = \sigma t \text{ x } \frac{\pi}{4} \text{ x } D_{min}{}^2 \quad (N)$$

13. Cylinder head fixation required preload for each bolt ($F_{Pre.}$),

$$F_{Pre} = K \text{ x } Fc + n \times \frac{Fs}{n} \quad (N)$$

Where,
K=Constant depends on bolt material and size
n = No. of bolts

Table 4: Typical values for K-

Sr.no	Condition	K value
1	Normal dry	0.2
2	Non-plated black finish	0.3
3	Zinc-plated	0.2
4	Slightly lubricated	0.18
5	Cadmium-plated	0.16

14. Residual preload on each bolt = $0.9 \text{ x } F_{Avail} - Fs \ (N)$

15. Factor of safety (FOS) = $\frac{S_{yt}}{\sigma t}$

Example-

Bolts are used to secure the cylinder, cylinder head, and gasket. The maximum pressure is 20 MPa, and the cylinder's ID is 115 mm. Four bolts with an M16*1.5 thread size secure the cylinder head to the cylinder. Preload of 70 KN is first provided by each bolt. Steel is used for the gasket and bolts. The cylinder head's material is GCI grade 25. Calculate the bolt safety factor while accounting for the gasket's impact.
Below is information about the M16*1.5 bolt and the cylinder head,

Table 5: Length, diameter and area of each C/S of Bolt size M16*1.5

Bolt Specification	Length	Diameter	Area
Head to shank (L1)	10	16	201.06
Shank (L2)	140	14	153.93
Full thread (L3)	50	14.99	176.47
Collar	33		

Table 6:Cylinder head Bolt details

Bolt size	M16*1.5	Unit
Pitch	1.5	mm
No of Bolt around cylinder (n)	6	
Modulus of Elasticity bolt (steel)	210000	Mpa
Yield strength (S_{yt})	900	Mpa
Friction Coefficient (μ)	0.2	
Lead of head of thread (P)	1.5	mm
Pitch diameter of thread (Dp)	14.99	mm
Mean diameter of bolt head (Dm)	16	mm

Table 7: Cylinder Head details

Description	**Value**	**Unit**
Bore (D)	115	mm
Cylinder peak pressure (Ppeak)	20	Mpa
Modulus of Elasticity of cylinder head (Eh)	118000	Mpa
Modulus of Elasticity of Gasket (Eg)	190000	Mpa
Height of cylinder head (Hcyl)	115	mm
Cylinder head gasket thickness (Tg)	2	mm

Solution:

1.Stiffness of bolt (Kb),

$$Kb = \frac{E_b}{\frac{L1}{A1}+\frac{L2}{A2}+\frac{L3}{A3}}$$

$$= \frac{210}{\frac{10}{201.06}+\frac{140}{153.93}+\frac{50}{176.47}} \quad = 169.35 \text{ KN/mm}$$

2.Stiffness of cylinder head (K_h) ,

$$K_h = E_h \text{ x } \frac{A_{Eq}}{L_h}$$

Where,

L_h = Height of cylinder head= 115 mm

A_{Eq} = Equivalent area of cylinder head

It is difficult to predict the area of cylinder head compressed by the bolt hence It is assumed that a hollow circular area of (3D) and (D) as an outer and inner diameters respectively is under the grip of the bolt.

$$A_{Eq} = \frac{\pi}{4}[(3D)^2 - D^2] = 2\pi D^2 = 2\pi 16^2 = 1608.49 \text{ mm}^2$$

3.Stiffness of cylinder head (K_h)= E_h x $\frac{A_{Eq}}{L_h}$

$$=118 \text{ x } \frac{1608.49}{115}$$

= 1650.45 KN/mm

4.Stiffness of Gasket (K_g) ,

$$K_g = E_g \text{ x } \frac{A_{Eq}}{L_g}$$

Where,

$L_{g=}$ Height of gasket = 2 mm

A_{Eq} = Equivalent Area of Gasket

Stiffness of Gasket (K_g) $=190 \times \frac{1608.49}{2}$

$= 152807.06$ KN/mm

5.Combined stiffness= $\frac{1}{K_c} = \frac{1}{K_h} + \frac{1}{K_C} + \frac{1}{K_g}$

$$\frac{1}{K_c} = \frac{1}{1650.45} + \frac{1}{1650.45} + \frac{1}{152807.06}$$

Kc = 820.81 KN/mm

6. Resultant bolt load,

$$\frac{Kb}{Kb+Kc} = \frac{169.35}{169.35+820.81} = 0.1710$$

Each bolt is initially tightened with a preload (F)=70 KN.

7.Cylinder head fixation required preload for each bolt (F_{Pre}) $=K \times Fc + n \times \frac{Fs}{n}$

Where,

Fc =Maximum combustion force,

Fc $=\frac{\pi}{4} \times D^2 \times P_{Peak} = \frac{\pi}{4} \times 115^2 \times 20 = 207711.85$

Fs = Loss of preload due to complete connection,

(Fs) = 1.3×Fg

Fg = Loss of preload due to gasket seating only

$F_g = \frac{0.1}{\frac{1}{K_b}+\frac{1}{K_h}} = \frac{0.1}{\frac{1}{169.35}+\frac{1}{1650.45}}$ = 15.35 KN = 15350 N

Hence,

(Fs) = 1.3×15350 = 19955 N

Cylinder head fixation required preload for each bolt,

(F_{Pre})= 0.18 x 207711.85+4 x 19955/4 = 57343.133 N

The resultant load on the bolt is given by,

$F_{Res.} = F + F_{Pre} \left(\frac{Kb}{Kb+Kc}\right)$

F_{Res}. =70000+57343.133 x 0.1710 = 79805.67 N

Resultant tensile stress in the bolt $\sigma t = \frac{F_{Res}}{\frac{\pi}{4} \times D^2} = \frac{79805.67}{\frac{\pi}{4} \times 16^2} = 396.92$

Factor of safety = (FOS) = $\frac{S_{yt}}{\sigma t} = \frac{900}{396.92} = 2.26$

IV. Conclusion

The design of a cylinder head gasket is a critical aspect of engine design. The design factors to consider include gasket material selection, thickness, shape, and the inclusion of features like fire rings, coolant passages, and oil passages. The material used in the gasket should be able to withstand high temperatures, pressures, and chemical exposure while maintaining its sealing properties. The thickness should be optimized to provide sufficient compression and sealing without interfering with engine performance. The pre-stressing of bolts is an important parameter to consider when designing a cylinder head gasket. Pre-stressing refers to the intentional application of tension to the bolts that secure the cylinder head to the engine block before the gasket is compressed. This tension helps to create a clamping force that ensures a tight and secure seal between the cylinder head and the engine block and also maintains the integrity of the gasket's seal under the high pressures and temperatures experienced in the combustion chamber. It prevents the gasket from being squeezed out or losing its compression, which can lead to leakage of combustion gases or coolant due to gasket failure and subsequent issues such as loss of compression, overheating, and potential engine damage. Therefore, considering the pre-stressing of bolts is an important parameter in the design of a cylinder head gasket. Thus, information about the material selection of cylinder head gaskets with different gasket types and gasket joint calculations to determine loss of preload due to gasket seating, loss of preload due to complete connection, and available preload after assembly is provided in this chapter. Additionally, the theoretical formula for maximum tightening torque, torsional stress generated in the smallest cross-sectional area of the bolt, and the necessary preload on each bolt for cylinder head fixation.

V. References

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