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MODELING AND THERMAL ANALYSIS OF CYLINDER HEAD GASKET

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Abstract: Cylinder head gasket is used to improve the efficiency of automobile engines by reducing the wastage in heat transfer between coolant and walls of a cylinder. The cylinder head gasket should be designed in such a way that it creates sealing to the cylinder engine which should withstand the temperature generated by an each combustion inside the cylinder at different loading conditions. The gas should not be escaped as the contact stresses subjected to the gasket should be analysed depending on the size and shape of the cylindrical head. In this research we design a gasket in an application called PROE, as the design is done by the taken specification according to the size of a cylinder. The designed model is saved as an IGES file and dumped into ANSYS for analysing the model when it is subjected to thermal and static loads. The results are taken out and area which experiences maximum load is shown.

***Keywords**: gasket, IGES, cylinder Gasket.*

I. INTRODUCTION

This report is an investigation into the efficiency of engine gasket sealing and the stress/strain behavior of a 2.0 L cylinder head under various loading conditions using contact theory and thermal stress analysis. Parametric analyses of the pre-stressing force of bolts between cold assembly and cold start conditions are also discussed. The results of this report could be regarded as a design reference for the automobile engine.

The main idea of this analysis is to introduce the pre-tension element into the simulation of the bolted assembly with the other components. Compared with the traditional method, the pre-tension element has many advantages over the method of controlling the raising and lowering of the temperature.

Owing to the complicated engine structure and the lack of experimental data on engine performance, especially of the cylinder head, there is little literature available that fully discusses the structural analysis of the cylinder head. In this report, the commercial FEM software, ANSYS, is introduced into the numerical simulation of the structural analysis.

1.1.Gasket Function

A cylinder head gasket is required to affect a seal between the cylinder head and block of a gasoline or diesel engine. It is an integral component of the engine and is required to perform many functions at the same time during engine operation. The head gasket must maintain the seal around the combustion chamber at peak operating temperature and pressure. The gasket must seal against air, coolants, combustion and engine oil at their respective peak operating temperature and pressure. The materials used and design employed must be thermally and chemically resistant to the products of combustion and the various chemicals, coolants and oils used in the engine.

When assembled, the head gasket becomes an important part of the total structure of the engine. It supports the cylinder head along with its operating components. It must be able to withstand the dynamic and thermal forces that are transmitted from the head and block. The type of engine application will be the determining factor in cylinder head gasket design. With engines ranging in size from one-cylinder gasoline fired engines up to twelve cylinder, turbocharged or supercharged high-compression diesels, the material and design of the gasket is paramount to its functional life span.

1.2.Gasket Design

Every application requires a unique cylinder head gasket design to meet the specific performance needs of the engine. The materials and designs used are a result of testing and engineering various metals, composites and chemicals into a gasket that is intended to maintain the necessary sealing capabilities for the life of the engine.

The most widely used materials are as follows:

- Steel and stainless steel of various grades and forms.
- Fibre based composite materials.
- Graphite in various densities.
- Chemical formulations containing polytetrafluorothylene, silicone, nitriles, neoprene, polymeric resins and others.

Engines are designed to operate within a ‘normal’ temperature range of about 190 to 220 degrees F. A relatively consistent operating temperature is absolutely essential for proper emissions control, good fuel economy and performance.

If the engine overheats and exceeds its normal operating range, the elevated temperatures can cause extreme stress in the cylinder head, which may result in a head gasket failure. This is especially true with

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aluminium cylinder heads because aluminium expands about two to three times as much as cast iron when it gets hot. The difference in thermal expansion rates between an aluminium head and cast iron block combined with the added stress caused by overheating can cause the head to warp. This, in turn, may lead to a loss of clamping force in critical areas and cause the head gasket to leak.

1.3. Gasket Analysis

Both the design and the development of the automobile engine are complicated processes. To acquire the best performance of an engine in any operating condition, including harsh natural environments, many analytical tools and experimental methods are used to find the optimum parameters for engine design. However, numerous measured results point out that the gas escaping from the engine not only affects the output efficiency of the horsepower substantially, but also pollutes the environment.

Therefore, the guarantee that the assembly between the cylinder head, bolts, and gasket is reliable and effective, through proper analytical procedures and tests becomes extremely important. Furthermore, the reduction of time and costs are considered in the development and design process of a new engine. The above-mentioned reasons are critical deciding factors in whether the goals of a new engine being developed are achieved or not.

To solve these foregoing issues, the thermal and structural analyses must be adopted in the engine design to save the time of actual modifications. in addition, in order to allow for the thermal stresses, which need to be blended into the structural analysis of the engine, the heat transfer analysis must take place prior to the structural analysis in order to calculate the results under loading conditions, such as hot firing, hot assembly, etc.

Due to the interface between the cylinder head and the gasket, as well as the interface between the cylinder head and the bolts, contact behavior takes place. A finite element analysis with different displacement method is used as solution to deal with the contact problems. However, the temperature inside the engine structure is produced through various operating processes and loading conditions. Consequently, the mechanical problems of thermal contact need to be considered for the gasket sealing process.

II. BACKGROUND THEORY

2.1. The Contact Theory

The Contact Theory assumes that at some scale the contact surfaces between the cylinder head, bolts, and gasket are not completely flat. During assembly, intermetallic contact is made at the asperities across the surfaces. Initially the cylinder head gasket goes through a plastically deformation process until the entire contact force is supported. The size of the plastically deformed gasket region is directly proportional to the contact pressure and inversely proportional to the material hardness.

The main focus of this report is to explore the efficiency of gasket sealing. In accordance with the distribution of contact pressure on the gasket, the location of the minimum contact pressure can be determined. The possibility of gas escaping is extremely high in the region of the weakest contact pressure. This blow-by of gas causesa low engine compression ratio resulting in poor engine efficiency. For more information on Contact Theory see Appendix A.

2.2. Thermal Stress

Mechanical stress induced on a cylinder head gasket expands or contracts in response to changes in temperature. Such stresses caused by a temperature change are known as thermal stresses. Due to the analyses of the operating conditions for the engine, both the hot assembly and the hot firing are included in this research. Hence, a heat transfer analysis concerning the cylinder head must be carried out prior to the structural analysis. According to the principle of conservation of energy, the heat condition equation in the material can be expressed as given in Figure 1 below, where T is temperature:

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

Figure 1: Heat Condition Equation

The temperature distribution in the material can be obtained with appropriate boundary conditions.

From the generalized Hooke's law, the strain components of the element including the thermal strains are as given in Figure 2 below, where σ is the normal stress, ε is the normal strain, E is the Young's modulus of elasticity, v is the Poisson's ratio, α is the coefficient of thermal expansion, ΔT is the incremental temperature, G is the shear modulus, τ is the shear stress, and γ is the shear strain.

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$$\varepsilon_x = [\sigma_x - \upsilon(\sigma_y + \sigma_z)]/E + \alpha\Delta T.$$
$$\varepsilon_y = [\sigma_y - \upsilon(\sigma_z + \sigma_x)]/E + \alpha\Delta T.$$
$$\varepsilon_z = [\sigma_z - \upsilon(\sigma_x + \sigma_y)]/E + \alpha\Delta T.$$
$$\gamma_{xy} = \tau_{xy}/G.$$
$$\gamma_{yz} = \tau_{yz}/G.$$
$$\gamma_{zx} = \tau_{zx}/G.$$

Figure 2: Equation for Strain Components of the Element

Material properties of individual engine components are given in Figure 3 below.

Exhaust valve (214N)	215	0.290	16.8	15.3
Inlet valve (EN52)	90	0.290	13.0	23.4
Cylinder head (Al alloy)	71	0.330	24.0	177.2
Cylinder block (Al alloy)	71	0.330	24.0	177.2
Liner (Cast iron)	107	0.295	11.7	0.0591
Bolt (SCM 435)	205	0.29	11.2	NA
Gasket	Multielastic	0.29	32	1.968E-4

Figure 3: Material Properties of Each Component of the Structural Analyses

III.IMPLEMENTATION METHODS

3.1. Finite Element Method

The Finite Element Method is a numerical analysis technique used to obtain solutions that are associated with physical and non-physical problems of cylinder head gasket sealing. The underlying premise of the method states that a complicated domain can be sub-divided into a series of smaller regions in which the differential equations are approximately solved. By assembling the set of equations for each region, the behavior over the entire problem domain is determined.

Each region is referred to as an ‘element’ and the process of subdividing a domain into a finite number of elements is referred to as ‘discretization’**.** Elements are connected at specific points, called ‘nodes’**,** and the assembly process requires that the solution be ‘continuous’ along common boundaries of adjacent elements.

The solution is determined in terms of discrete values of some primary field variables ϕ (e.g. displacements in **x, y** and **z** directions) at the nodes. The number of unknown primary field variables at a node is the degree of freedom at that node.

Once the element equations have been determined, the elements are assembled to form the entire domain **D**. The solution ϕ *(x, y)* to the problem becomes a piecewise approximation**,** expressed in terms of the nodal values of ϕ**.** A system of linear algebraic equations results from the assembly procedure.

3.2. Analysis Procedure

Stresses within the cylinder head gasket are as a result of external forces that act on the surface of the gasket (called ‘surface forces’) or forces that act throughout the volume (called ‘body forces’). Under the influence of the applied forces, the gasket will deform. It is assumed that the gasket behaves elastically and returns to its initial configuration when the applied loads are taken away. A measure of the relative deformation of the solid body is referred to as ‘strain’. In a Cartesian system, the components of strain are defined as shown in Figure 5 below:

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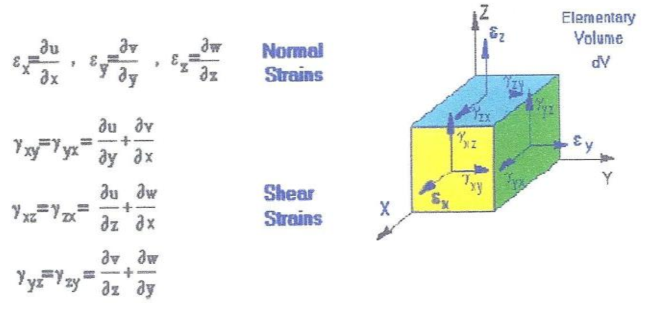

Figure 5: Components of Strain

- At a given point, ***P***, within the body, the strain can be calculated as functions of the ***u, v,*** and ***w*** displacement components. Assuming that the strains are sufficiently small such that second order terms can be neglected, this yields the strain displacement equations. The normal strains ***εx, εy,*** and ***εz*** are defined as the unit elongation of the body at a point in the direction of the respective ***x, y, z*** coordinate axes. The shearing strains measure the distort-ion of the angle between the various planes. For example, ***γxy*** measures the rotational distortion of the x-z and y-z planes. In general one can write therelationship in a matrix *form:* ***ε (x, y, z) = B δ (x, y, z).***

- The state of stress can be denoted by the normal stresses ***σx, σy, σz,*** and six components of shear stress. In a Cartesian coordinate system, these components are configured on an element of volume as shown in Figure 6 below, and related to the strains by, Hooke's law, where ***E*** is the modulus of elasticity, ***V*** is Poisson's ratio, and ***G*** is the modulus of rigidity. The more general stress-strain relationship that allows for different material properties can be written in a matrix form: ***σ*** *(x, y, z) = C* ***ε*** *(x, y, z).*

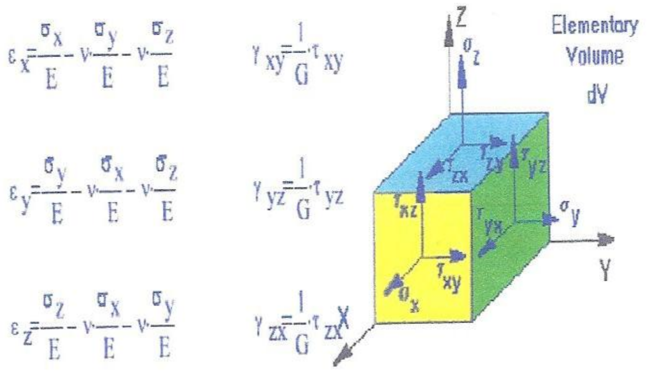

Figure 6: Normal Stresses and Shear Stress

3.3 Thermal Analysis

Thermal analysis is a form of analytical technique most commonly used in the branch of materials science where changes in the properties of materials are examined with respect to temperature. There are some assumptions concerning the thermal analysis of a cylinder head gasket which are as follows:

1. Owing to the fact that the coefficient of thermal conductivity of the gasket between the cylinder head and the block is extremely small, the gasket material is adopted as being adiabatic. Because of this assumption, the structure of the engine above the gasket is modeled to be calculated by finite element analysis.

2. The components such as the bolt, valve guide, valve seat, and so on, contribute little to the heat transfer of the temperature distribution of the whole cylinder head. Therefore, besides the inlet valve and the exhaust valve, other components are neglected in the thermal analysis. The maximum temperature occurs at the highest operating speed. Hence, the maximum horsepower output at 6,500 rpm is considered in this report. The maximum temperature appears at the area around the spark plug, and the next one occurs at the location between two adjacent combustion chambers.

3.4. Structural Analysis

According to the applied loadings originating from different categories of mechanics, this linear-elastic analytical procedure could further be divided into three load steps by means of the superposition principle for simulating various operating processes of the engine. The final results of the structural analysis are composed of the outputs of these three load steps.

Assembly Loadings

The major percentage of the loading applied to the engine is the assembly loading. This mainly refers to the pre-stressing of the bolts, and it plays an important role in preventing gas from escaping from the internal part of the engine. In other words, in addition to the design of the gasket itself, the efficiency of the sealing of the gasket depends mainly upon the correctness of the pre-stressing of the bolts. In order to avoid an insufficient sealing of the gasket, the bolts are pre-stressed in the range of 28-32kN. In the case of the assembly loadings, the structure of the whole cylinder is approximately half symmetrical hence the structural symmetric planes should have symmetric displacement

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boundary conditions. In addition, the displacements of the nodes at the bottom of the block are fixed to avoid the rigid body motion.

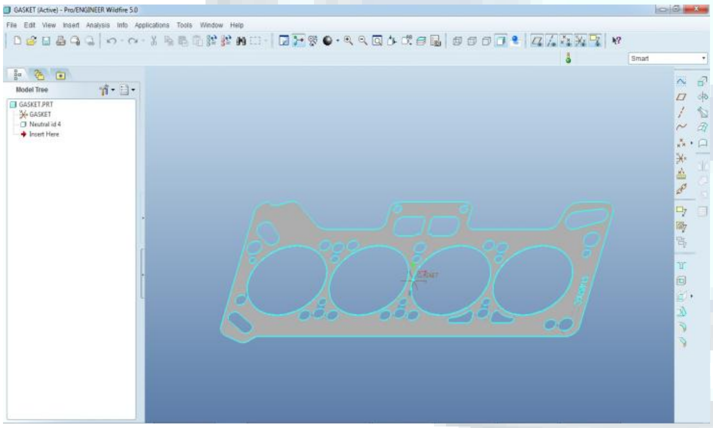
Thermal Loadings

In the case of thermal loadings, the nodal temperatures resulting from the prescribed thermal analysis are assigned to all corresponding nodes of the FEM model of the second cylinder head in order to calculate the thermal stress/strain of the cylinder head structure.

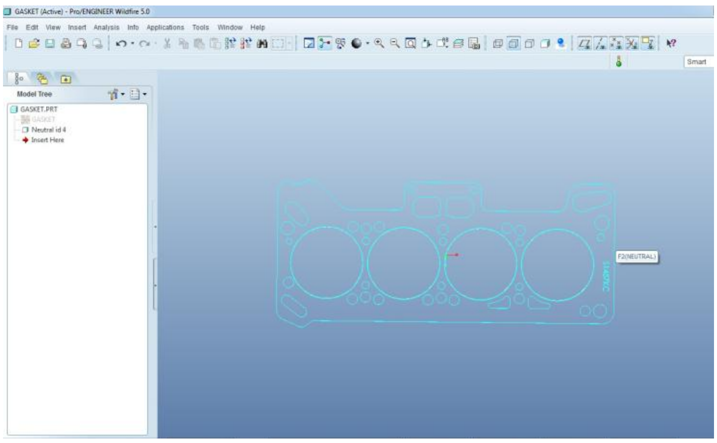
Gas Pressure

The gas pressure created as a result of the firing of the spark plug is imposed on the surface of the combustion chamber. However, the magnitude of the gas pressure varies with different durations of the cycle. For the steady state analysis, the average gas pressure is introduced into the loading conditions for the numerical simulation of cold starts and hot firing.

The following screen shot gives design of gasket in PROE

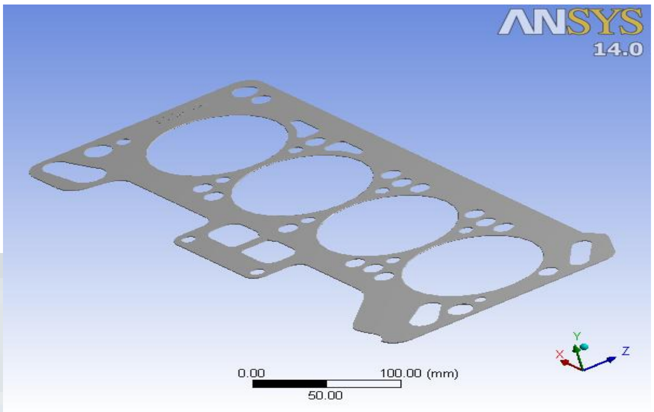


Oriental view of a cylinder head gasket



Wireframe view of a cylinder head gasket

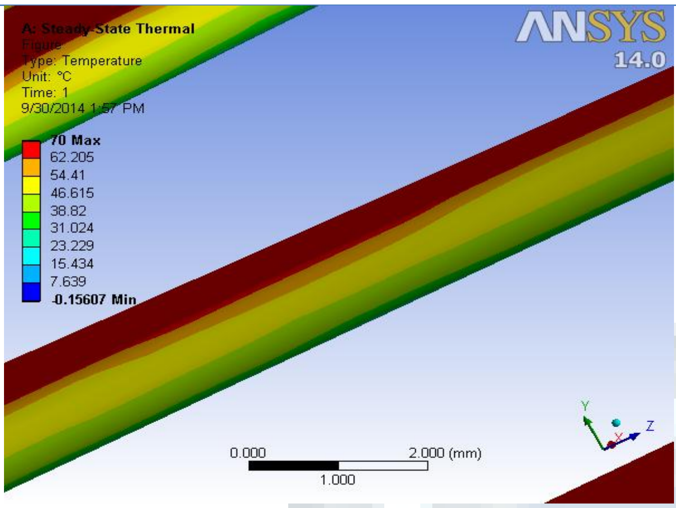
IV. EXPERIMENTAL RESULTS



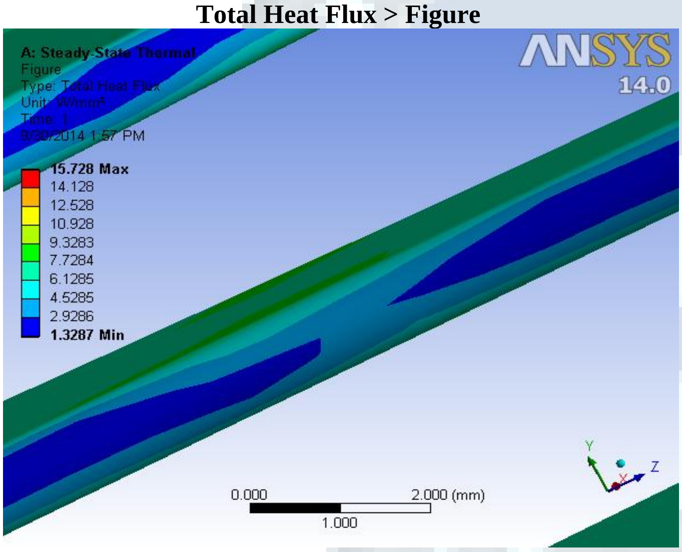
Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Results

Object Name	*Temperature*	*Total Heat Flux*	*Directional Heat Flux*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Temperature	Total Heat Flux	Directional Heat Flux
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Orientation			X Axis
Coordinate System			Global Coordinate System
Results			
Minimum	-0.15607 °C	1.3287 W/mm²	-5.2809 W/mm²
Maximum	70. °C	15.728 W/mm²	5.217 W/mm²
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	2		
Integration Point Results			
Display Option		Averaged	

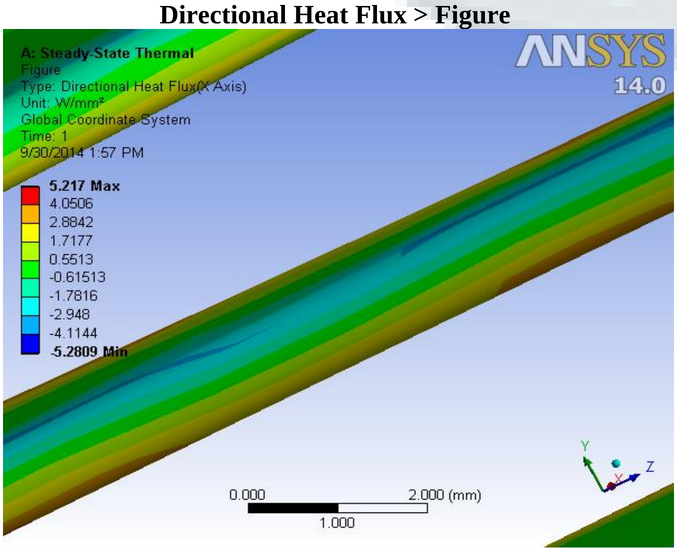
Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Temperature > Figure



Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Total Heat Flux > Figure



Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Directional Heat Flux > Figure



V. CONCLUSION

Every application requires a unique cylinder head gasket design to meet the specific performance needs of the engine. The materials and designs used are a result of testing and engineering various metals, composites and chemicals into a gasket that is intended to maintain the necessary sealing capabilities for the life of the engine

This project is done by creating a tri dimensional model CYLINDER HEAD GASKET and this model is generated by using design software PROE. PROE is useful for designing different number of models as per the dimensions, as it is aversatile application. The model should be analysed and measured which is designed in PROE. The obtained model is taken and geometric views are generated and following screenshots are shown. Analysis of the design is obtained by using ansys software and following results and tables are listed in this project.

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