STRESS ANALYSIS ON CYLINDER HEAD OF FOUR STROKE VARIABLE COMPRESSION RATIO DIESEL ENGINE

A project report submitted in partial fulfillment of the requirements for the award of the degree of

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6

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Submitted by

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CERTIFICATE

This is to certify that the project entitled "**STRESS ANALYSIS ON CYLINDER HEAD OF FOUR STROKE VARIABLE COMPRESSION RATIO DIESEL ENGINE**" describes the bonafide work done by D.BINDU PADMAVATHI (314126520045), D.BALAJI (314126520043), B.KRISHNA SAI (314126520025), G.PARDHA SARADHI (314126520064), J.V.VARUN TEJA (314126520067), in partial fulfilment for the award of Degree in Bachelor OF ENGINEERING in MECHANICAL ENGINERRING under my supervision and guidance during the academic year 2017-2018.

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ABSTRACT

The main aim of this work is to predict the design performance based on the stress/strain and behavior of cylinder head under various operating conditions. The effects of engine operating conditions such as combustion gas maximum internal pressure and temperature on the cylinder head have been analyzed. The maximum gas pressure vs crank angle are taken from the experimental set up of a variable compression ratio (VCR) Diesel engine . The analysis was carried out at compression ratio 18.5 using a finite element analysis (FEA) software package, which is use to simulate and predict the Von-Mises stresses and strain pattern and thermal distribution of the cylinder head structure .The geometrical modeling was carried out using CATIA and analysis is done on ANSYS software. In this investigation, structural and thermal analysis of the cylinder head highlight several areas of interest. The maximum stress is found not exceeding the material strength of cylinder head, and thus the basic design criteria, namely no yielding and no structural failure under firing load case are satisfied. This steady-state finite element method (FEM) stress analysis can play a very effective role in the rapid prototyping of the cylinder head. We have done analysis on five different materials. The results of the thermo-mechanical analysis show that when the engine is running, the stress in the region is compressive, caused by thermal loading and combustion pressure. The fatigue analysis is carried out to know the factor of safety and life of the cylinder head it indicates maximum life of 1×10^6 cycles at compression ratio 18.5 is determined through finite element analysis.

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Chapter 1

INTRODUCTION

The internal combustion engine converts chemical energy into useful mechanical energy by burning fuel. Chemical energy is released when the fuel-air mixture is ignited in the Combustion chamber. The gas produced in this reaction rapidly expands forcing the piston down the cylinder on the power stroke. The pistons reciprocate inside the cylinder; exhaust and intake ports open and close during various stages of the cycle. The movement of the piston up or down the cylinder makes up one stroke of the four stroke cycle. The linear motion is then converted to rotary motion by the crankshaft. The crankshaft is shaped to balance the pistons which are fired in a particular order to reduce engine vibration (typically for a 4-cylinder engine, 1-2-4-3 or 1-3-4-2). The flywheel then helps smooth out the linear movement of the pistons.

The diesel engine is one kind of Internal Combustion engine. An internal means "Inside" and combustion is Similar word for "Burning", So an Internal Combustion engine is simply one where the fuel is burned inside the cylinder where power is produced. That's very different from an External Combustion engine such as those used by old fashioned steam locomotives.

CYLINDER : The cylinder of an I.C. engine contains the working fluid and guides the piston. The cylinder has to withstand high temperature due to the combustion of fuel; So that, some arrangement must be provided to cool the cylinder. The cylinder engines are generally Air Cooled and Water Cooled.

AIR COOLED CYLINDER: Air cooled cylinder is commonly applicable for small engines say up to 20KW. In this type of cylinder fins are provided on the cylinder walls. Heat produced due to combustion in the engine cylinder and heat will be easily dissipated to air by help of provided fins.

WATER COOLED CYLINDER: In this type of cylinder water jackets are provided around the cylinder. The water when circulated through the jackets, It absorb heat of combustion. The water cooled cylinders mainly used in heavy engines having capacity above 20 KW.

CYLINDER HEAD : In an Internal combustion engine the cylinder head located above the cylinder on top of the cylinder block. It closes the top of the cylinder and forming the combustion chamber. This joint is sealed by use of head gasket. The head also gives space for the passages that feed air and fuel to the cylinder and that allow the exhaust to escape.

The cylinder head can also be a place to mount the valves, fuel injectors and spark plugs. The cylinder head are also either Air cooled or Water cooled.

AIR COOLED CYLINDER HEAD: In this type of cylinder head fins are provided on the outer surface of cylinder head. Heat produced due to combustion in the engine cylinder and heat will be easily dissipated to air by help of provided fins on cylinder head.

WATER COOLED CYLINDER HEAD: In this type of cylinder head water jackets are provided around the outer surface of cylinder head. The water when circulated
Through the jackets, it absorb the heat of combustion.

1.1. Parts of Internal Combustion Engine

The basic components for a combustion cycle in a four stroke engine are as follows

1. Cylinder
2. Piston
3. Valves
4. Connecting Rod
5. Crank
6. Crank Shaft
7. Flywheel

1.1.1 **Cylinder head**:

In an internal combustion engine, the cylinder head (often informally abbreviated to just head) sits above the cylinders on top of the cylinder block. It closes in the top of the cylinder, forming the combustion chamber. This joint is sealed by a head gasket. In most engines, the head also provides space for the passages that feed air and fuel to the cylinder, and that allow the exhaust to escape. The head can also be a place to mount the valves, spark plugs, and fuel injectors. Internally, the cylinder head has passages called ports or tracts for the fuel/air mixture to travel to the inlet valves from the intake manifold, and for exhaust gases to travel from the exhaust valves to the exhaust manifold. In a water-cooled engine, the cylinder head also contains integral ducts and passages for the engines' coolant - usually a mixture of water and antifreeze - to facilitate the transfer of excess heat away from the head, and therefore the engine in general.

Some engines, particularly medium- and large-capacity diesel engines built for industrial, marine, power generation, and heavy traction purposes (large trucks, locomotives, heavy equipment etc.) have individual cylinder heads for each cylinder. This reduces repair costs as a single failed head on a single cylinder can be changed instead of a larger, much more expensive unit fitting all the cylinders. Such a design also allows engine manufacturers to easily produce a 'family' of engines of different layouts and/or cylinder numbers without requiring new cylinder head designs.

The design of the cylinder head is key to the performance and efficiency of the internal combustion engine, as the shape of the combustion chamber, inlet passages and ports (and to a lesser extent the exhaust) determines a major portion of the volumetric efficiency and compression ratio of the engine.

1.2. Internal Combustion Engine

An internal combustion engine is an engine that operates by burning its fuel inside the engine. In contrast a steam engine burns its fuel outside the engine. The most common internal combustion engine type is gasoline powered. Others include those fueled by diesel, hydrogen, methane, propane, etc. Engines typically can only run on one type of fuel and require adaptations to adjust the air/fuel ratio or mix to use other fuels.

In a gasoline engine, a mixture of gasoline and air is sprayed into a cylinder. This is compressed by a piston and at optimal point in the compression stroke; a spark plug creates an electrical spark that ignites the fuel. The combustion of the fuel results in the generation of heat, and the hot gases that are in the cylinder are then at a higher pressure than the fuel-air mixture and so drive the piston back down. These combustion gases are vented and the fuel-air mixture reintroduced to run a second stroke. The outward linear motion of the piston is ordinarily harnessed by a crankshaft to produce circular motion. Valves control the intake of air-fuel mixture and allow exhaust gasses to exit at the appropriate times.

1.3. Diesel Engine

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel. which is injected into the combustion chamber during the final stage of compression. This is in contrast to spark ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to gasoline), which uses a spark plug to ignite an air-fuel mixture. The diesel engine is modeled on the Diesel cycle. The engine and thermodynamic cycle were both developed by Rudolf Diesel in 1897.

1.3.1. Two-Stroke Engine

The two-stroke type of internal combustion engine is typically used in utility or recreational applications which require relatively small, inexpensive, and mechanically simple motors (chainsaws, jet skis, small motorcycles, etc.).

The two-stroke engine is simple in construction, but complex dynamics are employed in its operation. There are several features unique to a two-stroke engine. First, there is a reed valve between the air-fuel intake and the crankcase. Air-fuel mixture enters the crankcase and is trapped there by the one-way reed valve. Next, the cylinder has no valves as in a conventional four stroke engine. Intake and exhaust are accomplished by means of ports - special holes cut into the cylinder wall which allows fuel-air mixture to enter from the crankcase, and exhaust to exit the engine. These ports are uncovered when the piston is in the down position.

Air-fuel mixture is drawn into the crankcase from the carburetor or fuel injection system through the reed valve. When the piston is forced down, the exhaust port is uncovered first, and hot exhaust gases begin to leave the cylinder. As the piston is now in the down position, the crankcase becomes pressurized, and when the intake port into the cylinder is uncovered, pressurized air-fuel mixture enters the chamber. Both the intake and exhaust ports are open at the same time, which means the timing and air flow dynamics are critical to proper operation. As the piston begins to move up, the ports are closed off, and the air-fuel mixture compresses and is ignited; the hot gases increase in pressure, pushing the piston down with great force and creating work for the engine.

The major components of two-stroke engines are tuned so that optimum airflow results. Intake and exhaust tubes are tuned so that resonances in airflow give better flow than a straight tube. The cylinder ports and piston top are shaped so that the intake and exhaust flows do not mix.

1.3.2. Four Stroke Engine

The four-stroke internal combustion engine is the type most commonly used for automotive and industrial purposes today (cars and trucks, generators, etc.). On the first (downward) stroke of the piston, fuel/air is drawn into the cylinder. The following (upward) stroke compresses the fuel-air mixture, which is then ignited - expanding exhaust gases then force the piston downward for the third stroke, and the fourth and final (upward) stroke evacuates the spent exhaust gasses from the cylinder.

The four-stroke cycle is more efficient than the two-stroke cycle, but requires considerably more moving parts and manufacturing expertise.

In CI engines fuel is injected into the combustion chamber at about 15° before T.D.C. during the compression stroke. For the best efficiency the combustion must complete within 15° to 20° of crank rotation after T.D.C. in the working stroke. Thus it is clear that injection and combustion both must complete in the short time.

In S.I engine mixing takes place in carburetor however in C.I engines this has to be done in the combustion chamber. To achieve this requirement in a short period is an extremely difficult job particularly in high speed C.I engines.

In order to achieve this, an organized air movement called swirl is provided to produce high relative velocity between the fuel droplets and the air.

a) Induction Stroke

The induction stroke in a Diesel engine is used to draw in a new volume of charge air into the cylinder. As the power generated in an engine is dependent on the quantity of fuel burnt during combustion and that in turn is determined by the volume of air (oxygen) present, most diesel engines use turbochargers to force air into the cylinder during the induction stroke.

b) Compression Stroke

The compression stroke begins as the inlet valve closes and the piston is driven upwards in the cylinder bore by the momentum of the crankshaft and flywheel.

The purpose of the compression stroke in a Diesel engine is to raise the temperature of the charge air to the point where fuel injected into the cylinder spontaneously ignites. In this cycle, the separation of fuel from the charge air eliminates problems with auto-ignition and therefore allows Diesel engines to operate at much higher compression ratios than those currently in production with the Otto Cycle.

c) Compression Ignition

Compression ignition takes place when the fuel from the high pressure fuel injector Spontaneously ignites in the cylinder. In the theoretical cycle, fuel is injected at TDC, but as there is a finite time for the fuel to ignite (ignition lag) in practical engines, fuel is injected into the cylinder before the piston reaches TDC to ensure that maximum power can be achieved. This is synonymous with automatic spark ignition advance used in Otto cycle engines.

d) Power Stroke

The power stroke begins as the injected fuel spontaneously ignites with the air in the cylinder. As the rapidly burning mixture attempts to expand within the cylinder walls, it generates a high pressure which forces the piston down the cylinder bore. The linear motion of the piston is converted into rotary motion through the crankshaft. The rotational energy is imparted as momentum to the flywheel which not only provides power for the end use, but also overcomes the work of compression and mechanical losses incurred in the cycle (valve opening and closing, alternator, fuel injector pump, water pump, etc.).

e) Exhaust Stroke

The exhaust stroke is as critical to the smooth and efficient operation of the engine as that of induction. As the name suggests, it's the stroke during which the gases formed during combustion are ejected from the cylinder. This needs to be as complete a process as possible, as any remaining gases displace an equivalent volume of the new charge air and
Leads to a reduction in the maximum possible power.

f) Exhaust And Inlet Valve Overlap

Exhaust and inlet valve overlap is the transition between the exhaust and inlet strokes and is a practical necessity for the efficient running of any internal combustion engine. Given the constraints imposed by the operation of mechanical valves and the inertia of the air in the inlet manifold, it is necessary to begin opening the inlet valve before the piston reaches Top Dead Centre (TDC) on the exhaust stroke. Likewise, in order to effectively remove all of the combustion gases, the exhaust valve remains open until after TDC. Thus, there is a point in each full cycle when both exhaust and inlet valves are open. The number of degrees over which this occurs and the proportional split across TDC is very much dependent on the engine design and the speed at which it operates.

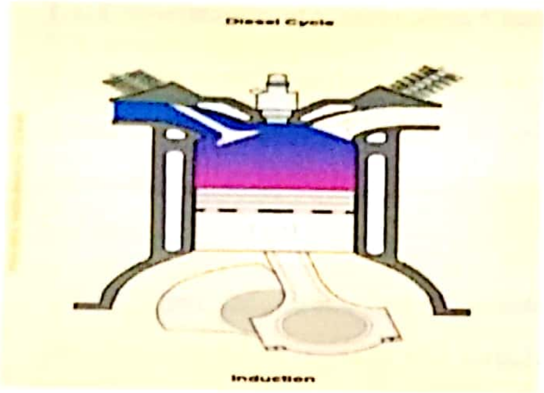


Fig 1.1 Suction Stroke

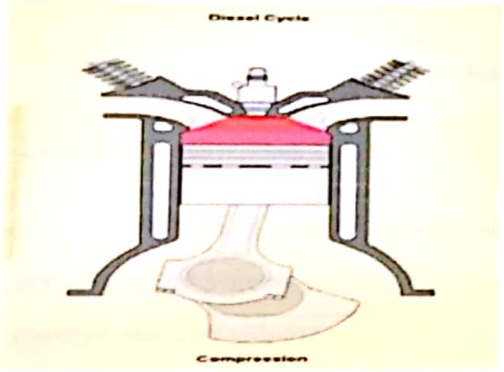


Fig 1.2 Compression Stroke

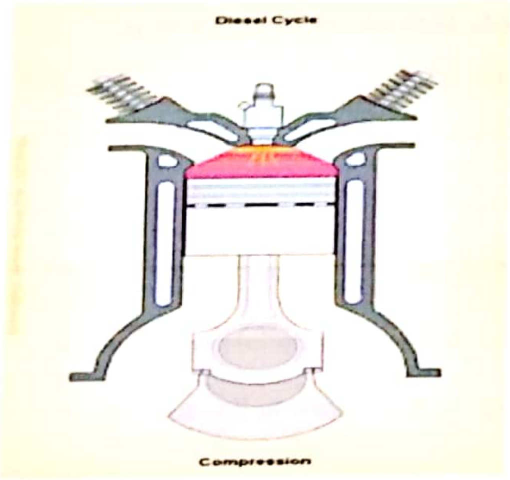


Fig1.3 Compression & Ignition

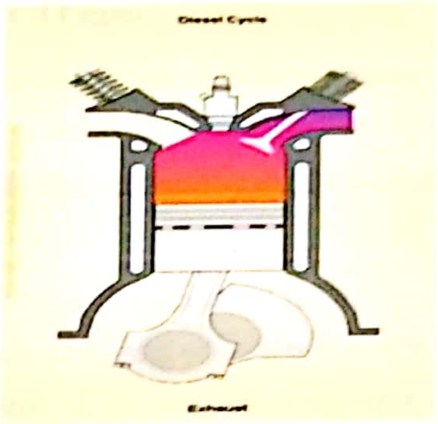


Fig 1.4 Exhausts Stroke

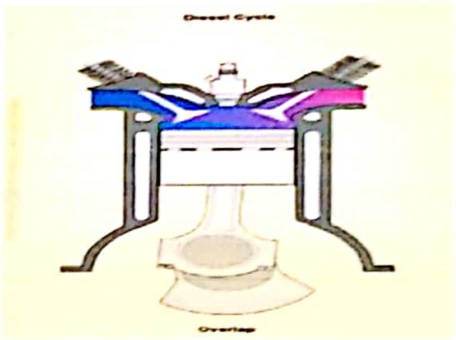


Fig 1.5 power stroke

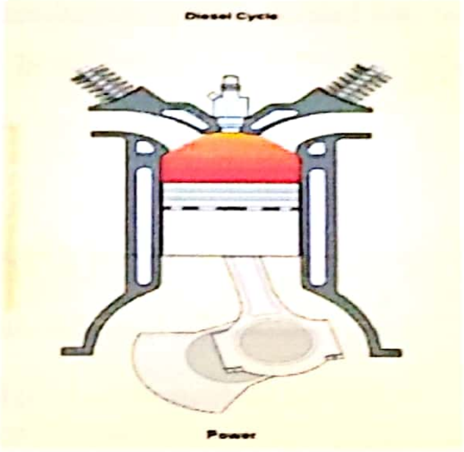


Fig1.6 Exhaust and Inlet Valve Over

1.4. Classification of Combustion Chambers of C.I Engine

The most important function of C.I engine combustion chamber is to provide proper chamber mixing of fuel and air in short time. In order to achieve this, an organized air movement called swirl is provided to produce high relative velocity between the fuel droplets and the air.

When the liquid fuel is injected into combustion chamber, the spray cone gets disturbed due to air motion and turbulence inside. The onset of combustion will cause an added turbulence that can be guided by the shape of the combustion chamber, makes it necessary to study the combustion design in detail.

C.I engine combustion chambers are classified into two categories

1.4.1. Direct Injection Type

This type of combustion chamber is also called an Open combustion chamber. In this type the entire volume of combustion chamber is located in the main cylinder and the fuel is injected into this volume.

1.4.2. Indirect Injection Type

In this type of combustion chamber, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel–injection is affected usually into the part of chamber located in the cylinder head.

These chambers are classified further into

- Swirl chamber in which compression swirl is generated.
- Pre combustion chamber in which combustion swirl is induced.
- Air cell in which both compression and combustion swirl are induced.

1.5. LOADS ACTING ON CYLINDER AND CYLINDER HEAD

I.) Inertia force on cylinder due to unbalance forces from piston and connecting rod setup.

II.) Vibration force in cylinder due to the speed variation in crankshaft.

III.) Thermal load on cylinder and cylinder head due to improper temperature distribution.

IV.) Mechanical load on cylinder head due to the improper stress distribution.

V.) Fatigue load due to cyclic load on cylinder head.

VI.) Load on cylinder due to the explosion of fuel gases

VII.) Load on cylinder due to compression of fuel gases.

Chapter 2

LITERATURE REVIEW

2.1 Literature Survey

The finite element analysis is performed to analyse thermal stress distribution at the real engine condition during combustion process. Cylinder head may appear deformation usually causes crack on the head. Due to deformation, stress concentration is caused on the cylinder head of the IC engine and the stress distribution on the cylinder head mainly depends on the deformation of cylinder head . The preliminary analysis presented in the paper was to compare the behavior of the combustion engine cylinder head at different compression ratios that is at 16.5,17.5,18.5 under thermal load. Finite element analysis is used to analyses stresses in a cylinder head of an internal combustion engine. The stresses due to combustion gas load only are considered so as to reduce the weight and hence to increase the power output of engine.

2.2 Scope Of Literature

S.S.Bhansali and N.D.Shirgire [1] this work include the vibration analysis of diesel engine cylinder liner considering combustion gas forces and cylinder liner temperature using finite element software ANSYS. Also Grey cast iron material is being tested in the software for this purpose. The output results were quite satisfactory to predict the behavior of deflection under different pressures. The combustion gas forces calculated for varying compression pressures. Results are presented the displacement vs. frequency shows the amplitude of vibration. By comparing the analytical results, the validity of the proposed analysis has been confirmed. Furthermore, this analysis is applied to evaluate the vibration of grey cast iron material along with increase in thickness, and revealing the closer response according to the material and vibration.

New thermo-mechanical analysis of cylinder head wasinvestigated by **M.Fadaei** et al. **[2]** In this paper the 3D model created by using Solid Works 2008. The mesh and analysis of cylinder head are constructed in ANSYS.

The FEM analysis of cylinder head was carried out by **Shixiong Li** et al.**[3]** They had found that the nose bridge area between the inlet and exhaust valves was very fragile on the cylinder head. For improving the overall structure of the cylinder head they had prepared the model first in the Pro/Engineer Wildfire 2.0 and after they had predicted the critical area and failure mode on cylinder head by help of finite element simulation. Finally the structure of nose bridge and other parts of cylinder head improved by using Finite Element Analysis software ANSYS 9.0.

Pradeep Mani Tripathi et al. [4] performed the thermal analysis on cylinder head. In which they had created model in Solid Works v12 and also they performed the two kinds of analysis like a steady-state thermal analysis and a transient thermal analysis. Also they used the FEM program for find out the temperature distribution on the parts of cylinder head. And they had changed the metal matrix composites in place of cast iron for reducing the weight and the analysis mentioned in this paper is handy in automotive applications

Thermal analysis and surface temperature prediction was studied by **Amit V. Paratwar** and **D.B. Hulwan.** [5] They had developed the heat transfer model for analyzing the thermal behavior of diesel engine cylinder. In this paper the steady state heat transfer analysis of cylinder liner and cylinder head was done using CFD analysis. And they marked that the theoretical values of the gas side heat transfer co-efficient with crank angle reaches peak value of 3000 W/m2k at 15° after TDC. After that they performed the thermal simulations and found that the maximum temperature present in the region of exhaust port and also at near the exhaust bridge. Finally by help of CFD analysis and by help of thermal simulations they obtained temperature drop by 7-10K in the critical zones as simulation result.

Nitin Kumar Sharma et al.[6] optimized the fins of the four stroke single cylinder petrol engine. They had observed that the maximum heat dissipation possible by providing the appropriate length with minimum thickness of fins and the maximum number of fins mounted on the cylinder. So by help of these all phenomenon they had obtained maximum possible cooling and better reliability of an engine at the maximum temperature.

F Zieher et al.[7] observed in current engine development program is that the design iterations resulting from durability testing for prediction of thermal mechanical fatigue (TMF) failure is necessary. At here complete life time simulation process is presented with emphasis on a newly developed material model for describing the constitutive behaviour of gray cast iron and compacted graphite iron under thermal cycling. The formulation of material model is based on a continuum-damage mechanics (CDM) approch in order to find out the tension or compression anomaly of cast iron. Thermal mechanical fatigue simulation of cylinder predicts the fatigue life and also predicts the stabilized stress/strain response at the valve bridge center.

Jun Hong et al.**[8]** studied about the optimal design of the engine cylinder head in which a simplified topological model composed of beam, shell and membrane elements is developed to simulate the metal cylinder head. Here finite element method is used for the study of load bearing mechanism of cylinder head during running condition of an engine. The behavior of all key components studied under stress and strain effect by parametric analysis. And the new optimization criterion is developed based on the Lagrange conditions which gives the ideal 'balanced point' among the main design parameters in terms of weight distribution of the key components the cylinder head. Finally in this way the optimization of cylinder head structure is implemented successfully.

Pravardhan S. Shenoy [9] investigates and compares fatigue behavior of forged steel and powder metal connecting rods and weight and cost reduction opportunities for a production of forged steel connecting rod. He notes that connecting rod made of C-70 steel is 10% lighter and 25% less expensive due to the steel's fracture crack ability.

Sreeraj Nair K., Kiran Robert, Shamnadh M.[10] studied the static analysis, thermal analysis, The analysis was carried out using a finite element analysis (FEA) software package, which is use to simulate and predict the Von- Mises stress and strain pattern and thermal distribution of the cylinder head structure during the combustion process in the engine and the geometry modeling was carried out using a popular computer-aided engineering tool, Solid works. The result can be used to determine the quality of the design as well as identify areas which require further improvement.

Mahammadrafik J. Meman, Amit B. Solanki, Akshay J. Parmar [11} has done" design modeling and analysis of structural strength of cylinder and cylinder head "The review of existing literature on design, modeling and analysis of cylinder and cylinder head is presented. 3D-model of cylinder and cylinder head were created using Pro/Engineer software and ANSYS was used to analyze the thermal and structural analysis. So finally design considerations, material specifications, failure analysis.

Martyn Roberts [12] has studied the potential benefits of Variable Compression Ratio (VCR) spark ignition engine, based on an examination of the relationship between Compression Ratio, BMEP and spark advance at light load and full load. Alternative methods of implementing VCR are illustrated and critically examined. System control strategies are presented. Potential manufacturing constraints are identified and their influence on system configuration is examined. Fuel economy benefits attainable from other technologies such as cylinder deactivation, camless valve operation and GDI are shown to be inferior to the use of downsized boosted engines. VCR is identified as the key enabling technology of such

Chapter 3

Material Properties Of Cylinder Head

Many early cylinder heads were manufactured from cast iron alloys primarily due to its high strength and low cost. But, as engine designs became more complicated, the weight of the engine (and thus the vehicle) had increased. Thus the need to come up with lighter alloys that were as strong as cast irons arose. One such material that was being used as a substitute was aluminum alloys. Together, these two metals were used exclusively to fabricate engine blocks. There are mainly five different materials

1.Compacted graphite iron (CGI- GJV450)

2.Aluminum alloy (319-T5)

3.Aluminum Alloy (A356-T6)

4. Grey Cast Iron (FG 200)

5. Magnesium Alloy (AMC-SC1)

3.1 Compacted Graphite Iron (CGI)

Compacted graphite iron (CGI).also known as vermicular iron graphite **(GJV, VG,**[1] **JV**[2] or **GGV)** from the German. The graphite in compacted graphite iron differs in structure from that in gray iron because the graphite particles are shorter and thicker.

- Excellent castability.
- Good machinability.
- Good wear resistance.
- High damping capacity which means it limits vibration in a finished casting.
- High thermal conductivity and is able to wick away heat.
- Excellent compressive strength.
- Good tensile strength.

Applications:

Cylinder blocks, cylinder heads, pumps, automobile components.

Table 3.1.1 mechanical & physical properties of compacted graphite iron:

Sl.no	Property name	Value
1	Density	7100 Kg/m^3
2	Poisons ratio	0.226
3	Yield strength	365 Mpa
4	Ultimate strength	450 Mpa
5	Thermal expansion	12 um/m-k
6	Youngs modulus	145 Gpa
7	Elongation	1.6%

Table 3.1.2 chemical composition of compacted graphite iron:

Elements	Weight Percentage
Pearlite	>90
Carbon(c)	3.6-3.8
Silicon(si)	2.1-2.5
Cerium(ce)	4.4-4.7
Manganese(mn)	0.2-0.4
Sulphur(s)	0.005-0.022
Magnesium(mg)	0.006-0.0014
ceMM	0.01-0.03
Copper(cu)	0.7-1.0
Tin (sn)	0.08-0.10

3.2 Aluminum Alloy (319-T5)

- It has excellent casting and machining characteristics.
- Corrosion resistance and weldability are very good.
- Mechanical properties are good in heat treated and non heat treated conditions.

Applications: Engine crankcases, gas and oil tanks, engine oil pans, engine parts.

Table 3.2.1 mechanical & physical properties of Aluminum Alloy (319-T5)

Sl.no	Property name	Value
1	Density	2790 Kg/m^3
2	Poisons ratio	0.336
3	Yield strength	180 Mpa
4	Ultimate strength	200 Mpa
5	Thermal expansion	22 um/m-k
6	Youngs modulus	72 Gpa
7	Elongation	1.8 %

Table 3.2.2 chemical composition of Aluminum Alloy (319-T5)

Elements	Weight Percentage
Aluminum(al)	85.8-91.5
Copper(cu)	3.0-4.0
Iron(fe)	<=1.0
Magnesium(mg)	<=0.10
Manganese(mn)	<=0.50
Nickel(ni)	<=0.35
Silicon(si)	5.50-6.50
Tin (sn)	0.25
Zinc(zn)	1.0

3.3 Aluminum Alloy (A356-T6)

- corrosion resistance is excellent.
- It has very good weldability characteristics.
- It has good castability.

Applications: Aircraft parts, impellers, pump housings, high velocity blowers.

Table 3.3.1 mechanical & physical properties of Aluminum Alloy (A356-T6)

Sl.no	Property name	Value
1	Density	2600 Kg/m^3
2	Poisons ratio	0.33
3	Yield strength	200 Mpa
4	Ultimate strength	270 Mpa
5	Thermal expansion	21 um/m-k
6	Youngs modulus	70 Gpa
7	Elongation	6 %

Table 3.3.2 chemical composition of Aluminum Alloy (A356-T6)

Elements	Weight Percentage
Silicon(si)	6.5-7.5
Ferrous(fe)	0.12
Copper(cu)	0.10
Magnesium(mg)	0.30-0.40
Manganese(mn)	0.05
others	5.50-6.50
Tin (sn)	0.2
Zinc(zn)	0.05

3.4 Gray Cast Iron (FG200)

While grey cast iron has less tensile strength and shock resistance than most other castings or even steal, it has compressive strength that is comparable to low- and medium-carbon steel. These mechanical properties are controlled by the size and shape of the graphite flakes present in the microstructure.

Applications:

Gears, hydraulic components, automotive suspension components, pumps.

Table 3.4.1 mechanical & physical properties of Gray Cast Iron (FG200)

Sl.no	Property name	Value
1	Density	7500 Kg/m^3
2	Poisons ratio	0.29
3	Yield strength	130 Mpa
4	Ultimate strength	240 Mpa
5	Thermal expansion	11 um/m-k
6	Youngs modulus	180 Gpa
7	Elongation	0.52 %

Table 3.4.2 chemical composition of Gray Cast Iron (FG200)

Elements	Weight Percentage
Silicon(si)	1.60-2.10
Carbon(total)	3.40 min
Sulphur(S)	0.12
Phosphours(p)	0.30-0.40
Manganese(mn)	0.60-0.90

3.5 Magnesium Alloy (AMC-SC1)

Magnesium alloys have been used in engines before, but not for cylinder blocks. Rather. The main advantage of this alloy is that the material is much lighter than cast iron and aluminum alloys and has the same strength as cast iron and aluminum alloys.

Applications: Powertrain Applications.

Table 3.5.1 mechanical & physical properties of Magnesium Alloy (AMC-SC1)

Sl.no	Property name	Value
1	Density	1790 Kg/m^3
2	Poisons ratio	0.35
3	Yield strength	114 Mpa
4	Ultimate strength	181 Mpa
5	Thermal expansion	26 um/m-k
6	Youngs modulus	43.9 Gpa
7	Elongation	6 -12 %

Table 3.5.2 chemical composition of Magnesium Alloy (AMC-SC1)

Elements	Weight Percentage
Aluminum(al)	8.0
Zinc(zn)	0.2
Lithium(li)	4.0
Neodymium(Nd)	0.2
Manganese(mn)	0.5
Yttrium(y)	0.5
Calcium(ca)	0.8
Stibium(sb)	0.4

Chapter 4

EXPERIMENTAL SETUP AND OBSERVATIONS

4.1 Experimental Setup:

Figure 4.1 represents the experimental set-up. The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Research engine connected to eddy current dynamometer. It is provided with necessary instruments for combustion pressure, crank-angle, airflow, fuel flow, temperatures and load measurements. These signals are interfaced to computer through high speed data acquisition device. The set-up has stand-alone panel box consisting of air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements. Rotameters are provided for cooling water and calorimeter water flow measurement.

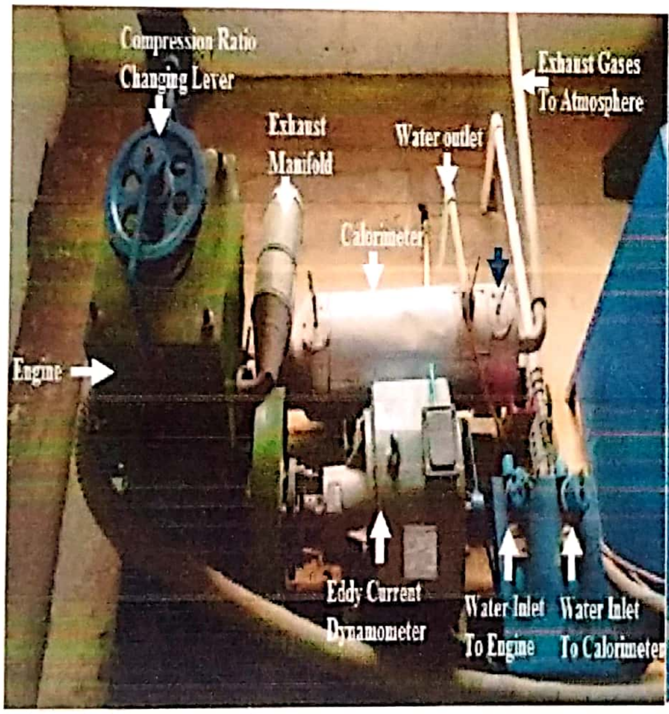


Fig4.1: Experimental Setup

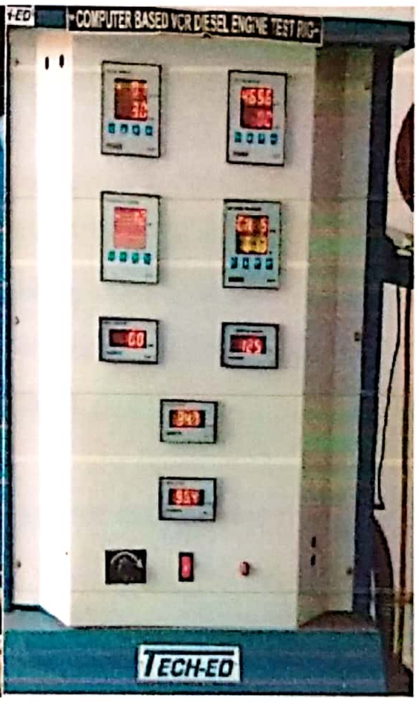


Fig4.2: Digital Indicator

4.2 Engine Specifications:

Table 4.2 engine specifications :

Parameters	Specifications
Make	Kirloskar
Type of engine	Single cylinder four stroke diesel engine
Bore of the engine	80mm
Stroke of the engine	110mm
Brake power	3.75kw
Speed(rpm)	1500rpm
Dynamometer	Eddy current dynamometer

4.3 Experimental Procedure:

- First, engine was warmed up and run for few minutes at 1500 rpm under no-load to reach stable operating conditions
- The water flow was adjusted for the engine cooling and calorimeter respectively.
- Then, as per experimental design a load level was set for engine operation. Once the engine reaches the steady-state condition, the engine was ready to present the baseline results.
- The load (torque) was varied in steps by means of the eddy-current dynamometer with the help of a manually controlled knob.

The following data were recorded manually as displayed in the engine controller at different loads:

1) Torque applied on the engine,
2) Temperatures of water at inlet and outlet of eng

3) Temperature of water and exhaust gas at inlet and outlet of exhaust gas calorimeter,

4) Fuel and air consumption were recorded,
5) Pressure of exhaust gas at the outlet of engine.

Composition of exhaust gas is measured using exhaust gas analyser.

This experimental measurement procedure was repeated for different engine loads. The load variations on the engine were conducted at 1500 ± 20 rpm.

4.4 Experimental Observations

Variable compression ratio four stroke diesel engine is run at three different compression ratios 16.5, 17.5 and 18.5 at different loads. The engine is run upto 60% of maximum load. Exhaust gas analyser is used to measure the flue gas composition in the exhaust line. The readings which recorded are tabulated as follows.

Crank angle(degrees)	**Pressure(bar)**		
	16.5	**17.5**	**18.5**
0	0	0	0
10	2.6	2.8	2.9
20	1.2	1.3	1.3
30	0.2	0.1	0.1
40	0	0	0
50	0	0	0
60	0	0	0
70	0	0	0
80	0	0	0
90	0	0	0
100	0	0	0
110	0	0	0
120	0	0	0
130	0	0	0
140	0	0	0
150	0	0	0
160	0	0	0
170	0	0	0

180	0	0	0
190	0	0	0
200	0	0	0
210	0	0	0
220	0	0	0
230	0	0	0
240	0	0	0
250	0	0	0
260	0	0	0
270	0.2	0	0
280	0.5	0.4	0
290	1.1	0.9	0.5
300	1.8	1.7	1.4
310	3.2	3	2.8
320	5.5	5.4	5.2
330	9.5	9.7	9.6
340	16.9	17.8	18.1
350	28.5	31.1	32.1
360	42.2	47.9	49.9
365	51.3	54.5	55.4
370	48	51.9	52.8
380	38.2	39. 2	39
390	26.3	27	26.5
400	18.6	18.7	18.1
410	13.2	13.2	12.6
420	9.5	9.7	9
430	7	7.3	6.6
440	5.4	5.6	4.9
450	4.2	4.4	3.7
460	3.3	3.5	2.8
470	2.7	2.8	2.1

480	2.2	2.3	1.6
490	1.9	2	1.3
500	1.6	1.7	1
510	1.5	1.5	0.9
520	1.4	1.4	0.8
530	1.3	1.3	0.7
540	1.3	1.3	0.7
550	1.4	1.4	0.8
560	1.3	1.3	0.7
570	1	0.9	0.3
580	0.7	0.5	0
590	0.3	0.2	0
600	0	0	0
610	0	0	0
620	0	0	0
630	0	0	0
640	0	0	0
650	0	0	0
660	0	0	0
670	0	0	0
680	0	0	0
690	0	0	0
700	1.1	0.8	0.6
710	2.7	2.5	2.4
720	0	0	0

Table 4.3: Experimental Readings of Pressure and Crank Angle of Variable Compression Ratio Diesel Engine at Compression Ratios 16.5, 17.5 and 18.5[9]

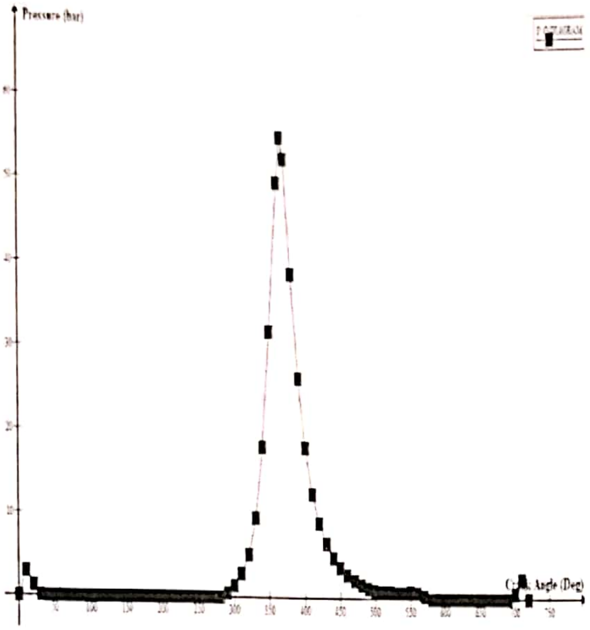


Fig4.3 pressure vs crank angle at CR 18.5

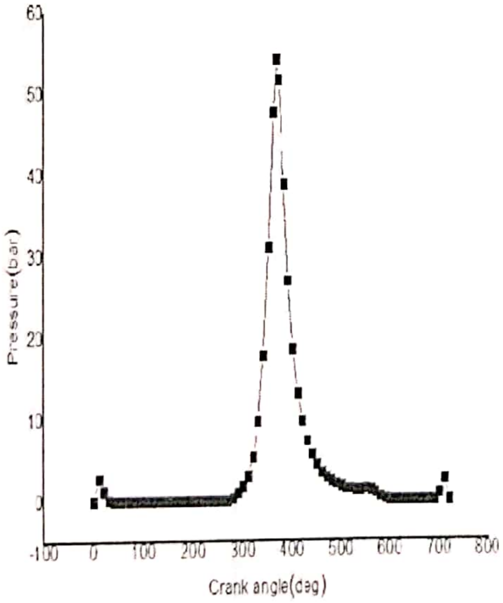


Fig 4.4 pressure vs crank angle at CR 16.5

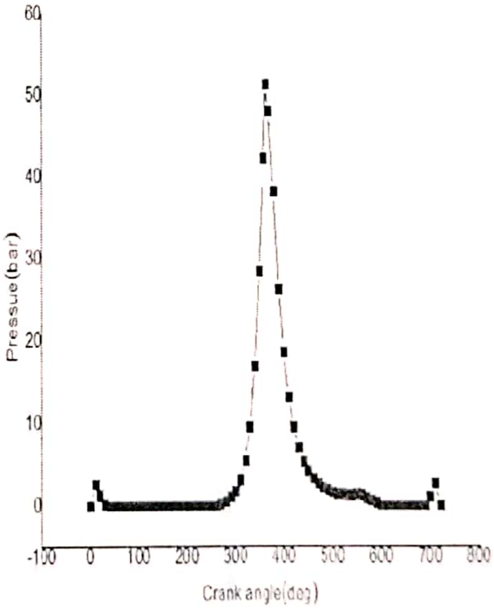


Fig 4.5 pressure vs crank angle ar CR 17.5

Chapter 5

GEOMETRY MODELING

5.1 INTRODUCTION TO CATIA

CATIA, stands for Computer Aided Three-dimensional Interactive Application, It is the most powerful Knowledge based and widely used CAD (computer aided design) software of its kind in the world. CATIA has been created by Dassault Systems of France and is marketed & technically supported worldwide by IBM..The most commonly CATIA users are generally Aerospace, Appliances, Architecture, Automotive, Construction, Consumer Goods, Electronics, Medical, Furniture, Machinery, Mold and Die, and Shipbuilding industries. CATIA has played a major role in NASA's design of the various Space equipments. Beside this it has also been used as Vital tool for designing "jet-fighter" aircraft, aircraft carriers, helicopters, tanks and various other forms of weaponry extensively used by the Defense Sector. CATIA is used throughout the North American and European continents, as well as Australia. Apart from this CATIA is increasingly being used by Asian countries like India, Japan etc.

French Dassault Systems is the parent company and IBM participates in the softwares and marketing, and catia is invades broad industrial sectors, and has been explained in the previous post position of CATIA between 3d modeling software programs.

Fig5.1 Different Modules In Catia

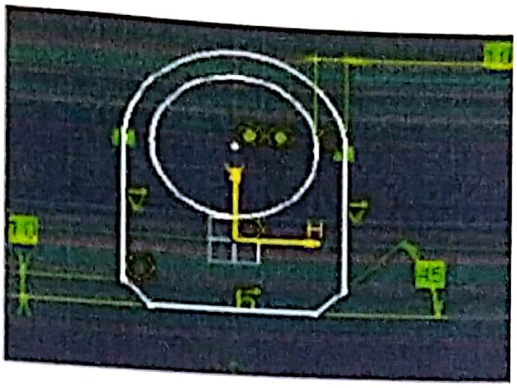


Fig 5.2 Sketcher Example In Catia

5.2 Sketcher: This module is responsible for the implementation of two-dimensional shapes, in preparation for make a three-dimensional commands on it.

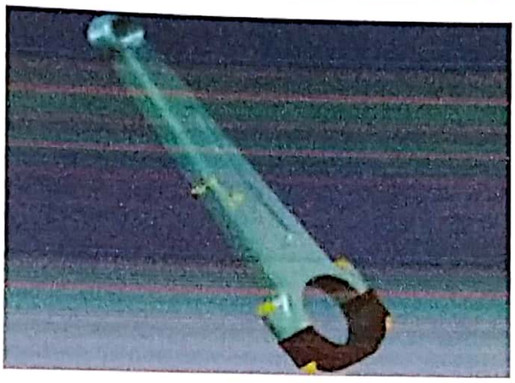


Fig 5.3 Part Design In Catia

5.3 Part Design: This module is responsible for converting two-dimensional graphics to three-dimensional objects which is most famous in Catia and is closely linked with sketcher module. The part design Module it is considered from most important modules, that used by the designer to get the additional advantage from cad programs, which is stereotaxic drawing or three-dimensional drawing.

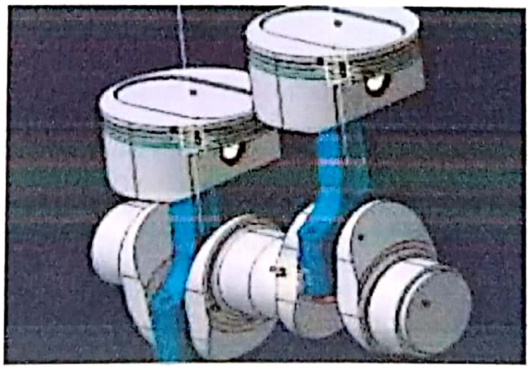


Fig 5.4 Parts Assembly In Catia

5.4 Assembly: This module is responsible for assembling the parts previously produced in Part Design, and it is most important for those who work in the field of machinery design or design in general, because it is the one who shows the inter-relationships between the parts of the machine or any mechanical establishment.

5.5 Drafting: This module is responsible, for converting what you see on the screen to standard engineering drawings can be traded in the workshop for manufacturing or save them for documentation.

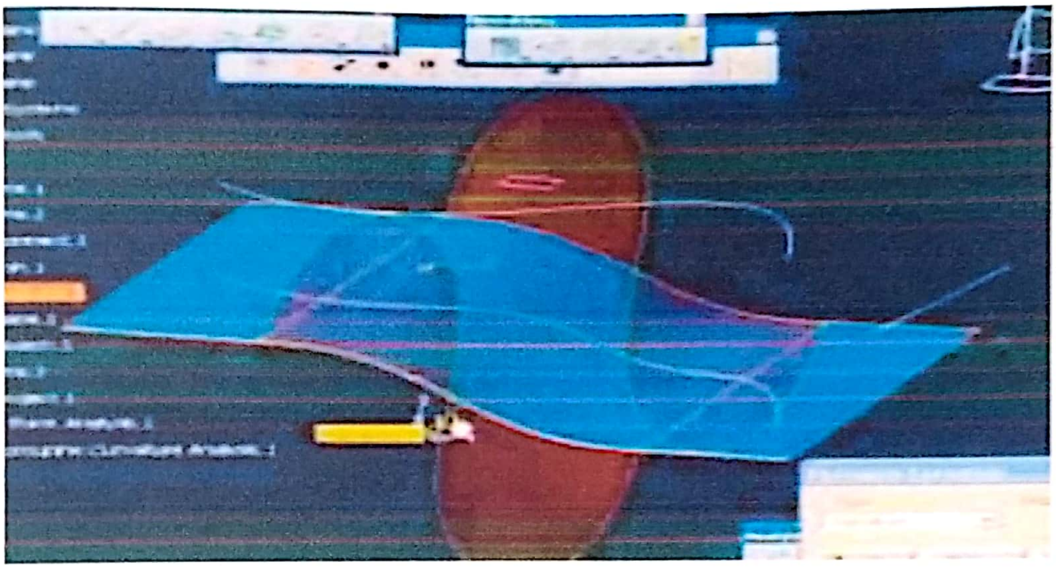


Fig5.5 Surface And Wireframe In Catia.

5.6 Surface and Wire Frame: With this module surfaces can be drawing with zero size and weight and has its uses in the aerospace, automotive, ships and Mold Design.

5.7 Simulation: This module is responsible for obtaining a similar movement of the natural movement, which is expected to occur during the actual operation of the machine or mechanical establishment whatever.

5.8 Free Style: Which is a free drawing, product designers needs it, such as Mobile or furniture or antiques designers .and other modules such as

5.9 Sheet Metal, Mold Design, Welding, Aerospace Sheet Metal:

The surprise is that all of the above follows the one field which is mechanical design field , while there are other fields such as:

1. **Analysis**
2. **Machining**
3. **Ergonomics**

Each of them containing modules, even electronic circuit design, that is mean CATIA have too many modules, and it is covers almost everything you need, so I prefer to work on it more than others.

CATIA is considered as a CAM program, in addition to it is CAD program, in the meaning that you can export files to CNN machines and then manufactured, CATIA Also supports graphics from other programs such as AutoCAD, for example, it is possible to copy a drawing from AutoCAD and enter it to CATIA and then make on it CATIA operations, CATIA files can be kept with dwg extension which is supported by AutoCAD or the default extension has.

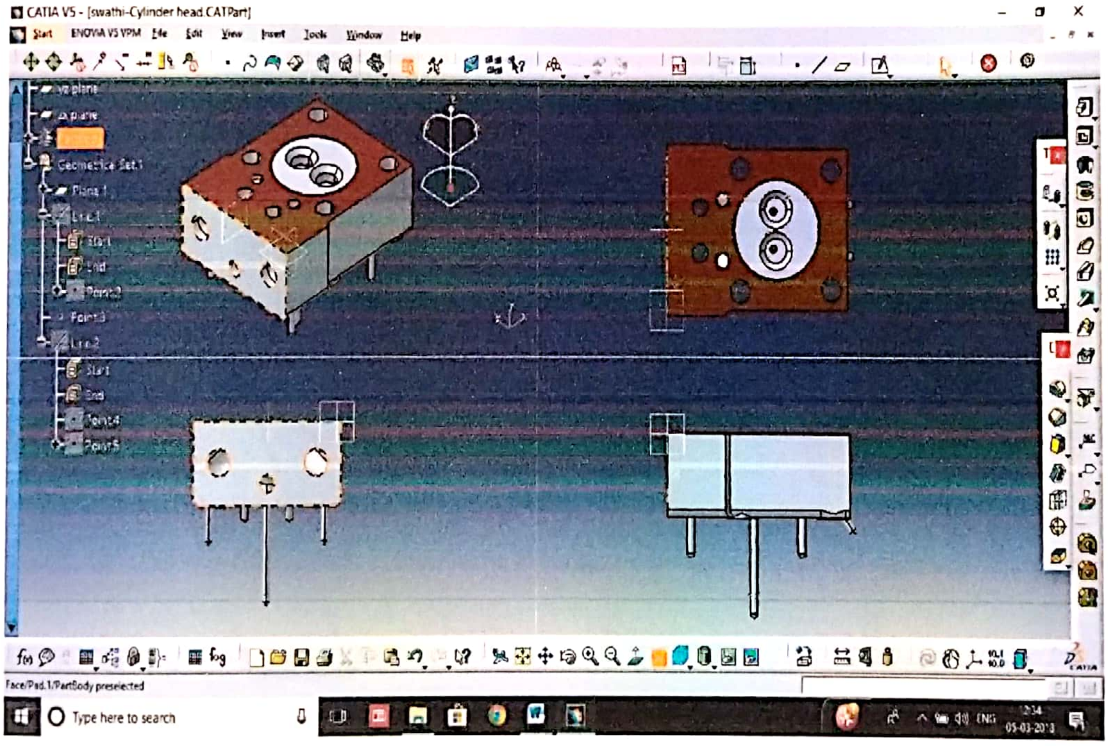


Fig 5.6 Cylinder head geometry model

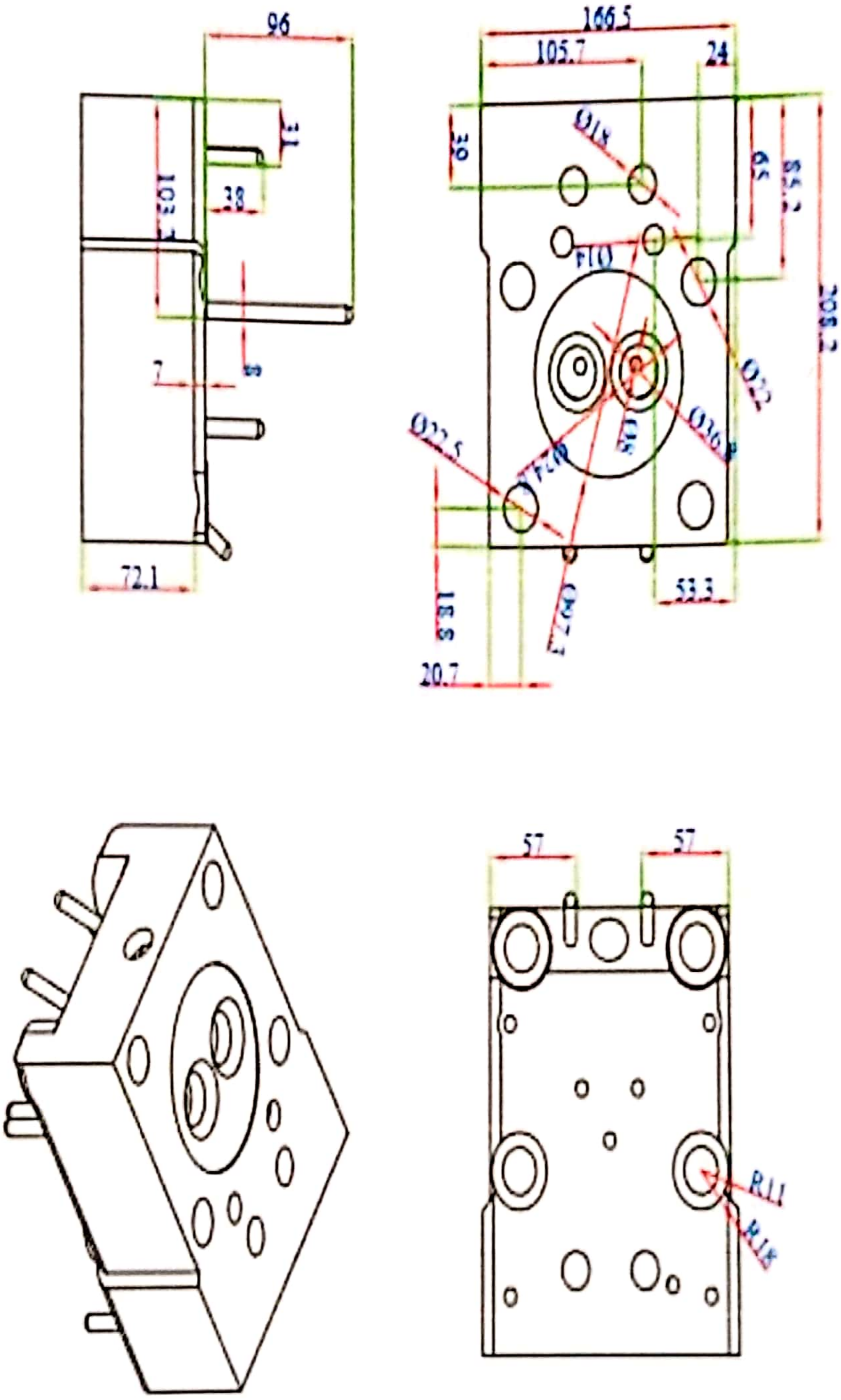


Fig 5.7 2D model of cylinder head

Chapter 6

FINITE ELEMENT ANALYSIS

6.1. Introduction to Finite Element Analysis

Approximate solutions to a wide variety of engineering problems although originally developed to study stresses in complex airframe structures, it has since been extended and applied to the broad field of continuum mechanics. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering schools and industry. The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. Advances in computer technology and CAD systems, has led to increased use of FEM in research as well as industry as complex problems can be modeled and released with relative ease.

In more and more engineering situations today, we find that it is necessary to obtain approximate numerical solutions closed-form solutions. For example, we may want to find the load capacity of a plate that has several stiffeners and odd-shaped holes, the concentration of pollutants during non-uniform atmospheric conditions, or the rate of fluid flow through a passage of arbitrary shape. Without too much effort, we can write down the governing equations and boundary conditions for these problems, but we see immediately that no several approximate numerical analysis methods have evolved over the years; a commonly used method is the finite difference scheme. The familiar finite difference model of a problem gives a point wise approximation to the governing equations. This model (formed by writing difference equations for an array of grid points) is improved as more points are used. With finite difference techniques we can treat some fairly difficult problems but, for example, when we encounter irregular geometries or an unusual specification of boundary conditions, we find that finite difference techniques become hard to use. Simple analytical solution can be found. The difficulty in these three examples lies in the fact that either of the geometry or some other feature of the problem is irregular or "arbitrary." Analytical solutions to problems of this type seldom exist; yet these are the kinds of problems that engineers are called upon to solve.

Unlike the finite difference method, which envisions the solution region as an array of grid points, the finite element method envisions the solution region as built up of many small, interconnected sub regions or elements. A finite element model of a problem gives a piecewise approximation to the governing equations. The basic premise of the finite element method is that a solution region can be analytically modeled or approximated by replacing it with an assemblage of discrete elements. Since these elements can be put together in a variety of ways, they can be used to represent exceedingly complex shapes.

As an example of how a finite difference model and a finite element model might be used to represent a complex geometrical shape, consider the cylinder head cross section in Figure 4.1. For this device we may want to find the distribution of displacements and stresses for a given force loading or the distribution of temperature for a given thermal loading. The interior coolant passage of the head , along with its exterior shape, gives it a no simple geometry. A uniform finite difference mesh would reasonably cover the cylinder head . It is 10 nodded tetrahedral elements and the number of countable nodes is 67121 and the number of elements is 53806.

Basic geometry of the cylinder head:

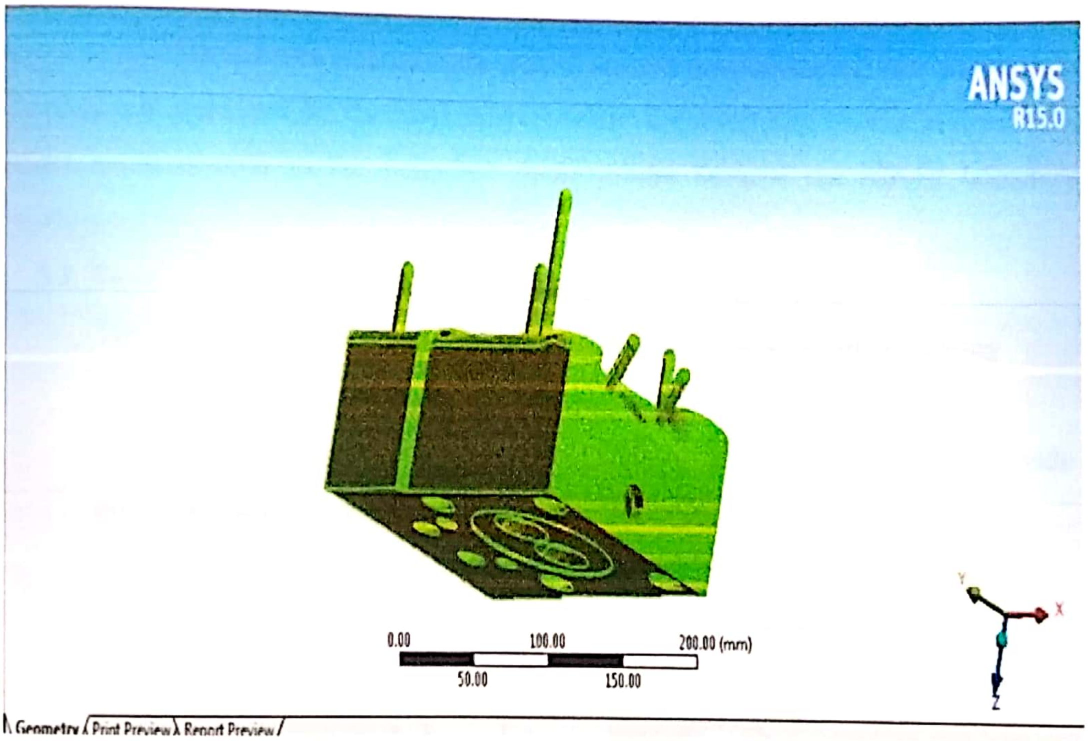


Fig 6.1 geometry of cylinder head

Meshing of cylinder head

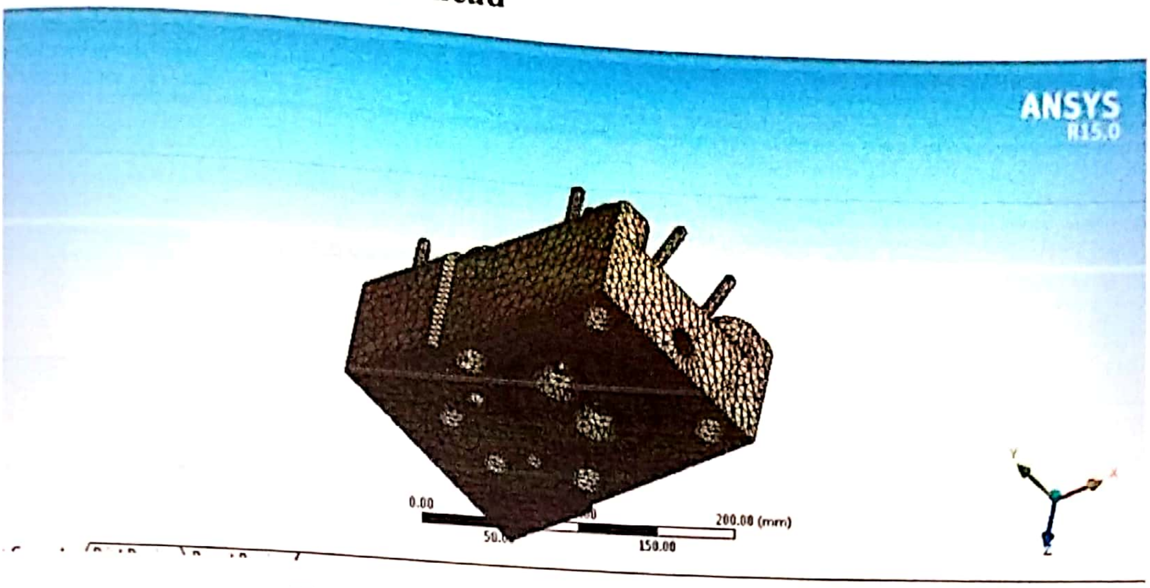


Fig 6.2 meshing of cylinder head

On the other hand, the finite element model (using the simplest two-dimensional element—the triangle) gives a better approximation to the region. Also, a better approximation to the boundary shape results because the curved boundary is represented by straight lines of any inclination.

5.2. Basic Steps in the Finite Element Analysis

The basic steps involved in finite element analysis consist of the following

a)Pre-Processing Phase

Create and discretize the solution domain into finite elements i.e. subdivide the problem into nodes and elements.

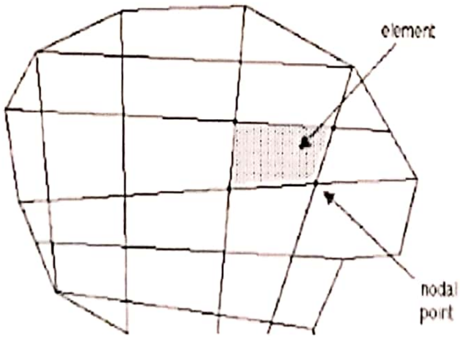


Fig 6.3 Discretization of Real Continuum with Node and Element

- Assume a shape function to represent the physical behavior of an element; that is an approximate continuous function is assumed to represent the solution of an element.
- Develop equations for all the elements in the mesh.
    - These generally take form
    - [K]{U} = {F}
    - Where '[K]' is a square matrix, known as stiffness matrix
    - '{U}' is the vector of (unknown) nodal displacements or temperature
    - '{F}' is the vector of applied nodal forces
- Assemble the elemental equations to obtain the equations of the whole problem. Construct the global stiffness matrix.
- Apply boundary conditions, initial conditions, and loading.

a) Solution Phase

Solve a set of linear or nonlinear algebraic equations simultaneously to obtain nodal results of primary degrees of freedom or unknowns, such as displacement values at different nodes in structural problem or temperature values at different nodes in heat transfer problem.

b) Post processing phase

- Computation of any secondary unknowns or variables e.g. the gradient of the solution.
- Interpretation of the results to check whether the solution makes sense.
- Tabular and/or graphical presentation of the results.

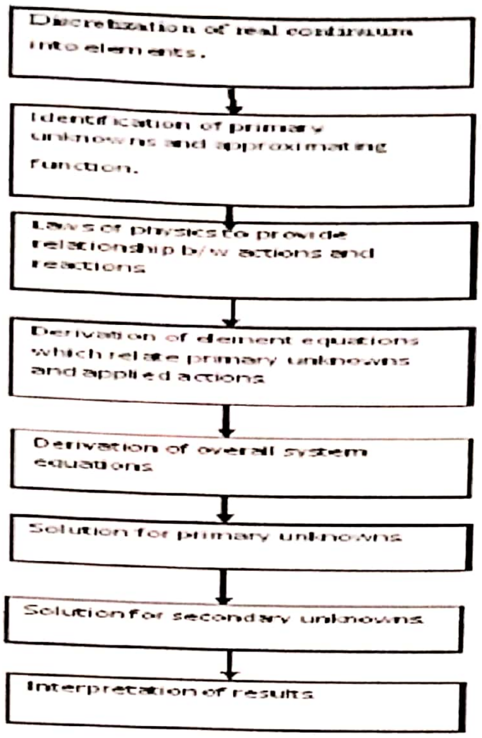


Fig 6.4 Tabular presentation of results

6.3. Introduction to Ansys Workbench

ANSYS Workbench is the framework upon which the industry's broadest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user every step of the way. Even complex multi physics analysis can be performed with drag-and-drop simplicity.

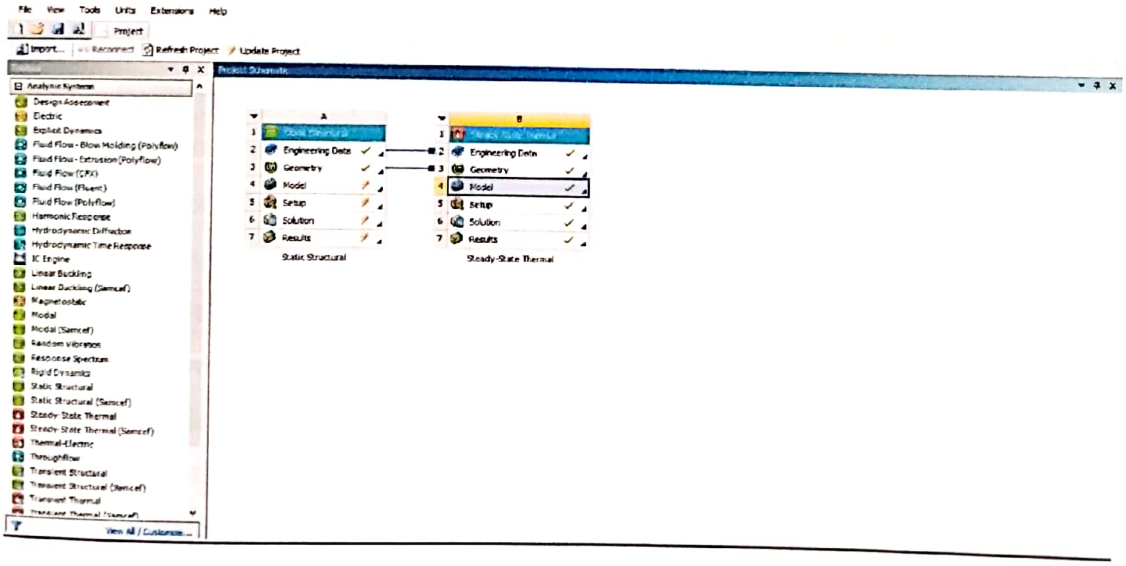


Fig 6.5 Workbench 15.0 Interface

The ANSYS Workbench platform automatically forms a connection to share the geometry for both the fluid and structural analysis, minimizing data storage and making it easy to study the effects of geometry changes on both analyses. In addition, a connection is formed to automatically transfer pressure loads from the fluid analysis to the structural analysis.

The ANSYS Workbench interface is arranged into two primary areas: The toolbox and the project Schematic. The toolbox contains the system templates that you can use to build a project. The project Schematic is the area if the interface where you will manage your project. The new project schematic view shows an overall view of the entire simulation project. Engineering intent, data relationships and the state of the entire project are visible at a glance, even for complex analyses involving multiple physics in addition to this, you will see a menu bar and a toolbar with frequently used functions. You can also use context menus, accessible via a right- mouse click, on schematic items, and cells. Context menus provide capabilities to add to and modify projects. The entire process is persistent. Changes can be made to any portion of the analysis and the ANSYS Workbench platform will manage the execution of the required applications to update the project automatically, dramatically reducing the cost of performing design iterations.

6.3.1. Ansys Workbench Features

- Bidirectional, parametric links with all major CAD systems.
- Integrated, analysis-focused geometry modeling, repair, and simplification via ANSYS Design Modeler.
- Highly-automated, physics-aware meshing.
- Automatic contact detection.
- Unequalled depth of capabilities within individual physics disciplines.
- Unparalleled breadth of simulation technologies.
- Complete analysis systems that guide the user start-to-finish through an analysis.
- Comprehensive multi physics simulation with drag-and-drop ease of use.
- Flexible components enable tools to be deployed to best suit engineering intent.
- Innovative project schematic view allows engineering intent, data relationships, and the state of the project to be comprehended at a glance.
- Complex project schematics can be saved for re-use.

- Pervasive, project-level parameter management across all physics.
- Automated what-if analyses with integrated design point capability.
- Adaptive architecture with scripting and journaling capabilities and API's enabling rapid integration of new and third-party solutions.

6.4. Structural Analysis

Structural analysis is probably the most common application of the finite element method. The term *structural* (or *structure)* implies not only civil engineering structures such as bridges and buildings, but also naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

6.4.1. Types of structural analyses

The seven types of structural analyses available in the ANSYS family of products are explained below. The primary unknowns (nodal degrees of freedom) calculated in a structural analysis are displacements. Other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

Structural analyses are available in the ANSYS/Multi physics, ANSYS/Mechanical, ANSYS/Structural, and ANSYS/Linear Plus programs only.

One can perform the following types of structural analyses

1) Static Analysis

Used to determine displacements, stresses, etc., under static loading conditions. It comprises of both linear and non-linear static analysis. Non-linearity can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

2) Model Analysis

Used to calculate the natural frequencies and mode shapes of a structure. Different mode extraction methods are available.

3) Harmonic Analysis

Used to determine the response of a structure to harmonically time-varying loads.

4) **Transient Dynamic Analysis**

Used to determine the response of a structure to arbitrarily time-varying loads. All non-linearity mentioned under Static Analysis above are allowed.

5) **Spectrum Analysis** An extension of the modal analysis, used to calculate stresses and strains due to a response spectrum or a PSD input (random vibrations).

6) **Buckling Analysis**

Used to calculate the buckling loads and determine the buckling mode shape. Both linear (Eigen value) buckling and nonlinear buckling analyses are possible.

7) **Explicit Dynamics Analysis**

ANSYS provides an interface to the LS-DYNA explicit finite element program and is used to calculate fast solutions for large deformation dynamics and complex contact problems.

- In addition to the above analysis types, several special-purpose features are available
  - Fracture mechanics
  - Composites
  - Fatigue
  - p-Method

6.5. Thermal Analysis

A thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are

- The temperature distributions
- The amount of heat lost or gained
- Thermal gradients
- Thermal fluxes

Thermal simulations play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses (that is, stresses caused by thermal expansions or contractions).

Only the ANSYS/Multi physics, ANSYS/Mechanical, ANSYS/Thermal, and ANSYS/FLOTRAN programs support thermal analysis.

The basis for thermal analysis in ANSYS is a heat balance equation obtained from the principle of conservation of energy. The finite element solution one performs via ANSYS calculates nodal temperatures and then uses the nodal temperatures to obtain other thermal quantities.

The ANSYS program handles all three primary modes of heat transfer: conduction, convection, and radiation.

6.5.1. Types of thermal analysis

ANSYS supports two types of thermal analysis

I. *A* **steady-state thermal analysis** determines the temperature distribution and other thermal quantities under steady-state loading conditions. A steady-state loading condition is a situation where heat storage effects varying over a period of time can be ignored.

II. *A* **transient thermal analysis** determines the temperature distribution and other thermal quantities under conditions that vary over a period of time.

6.6. Coupled-Field Analysis

A coupled-field analysis is an analysis that takes into account the interaction (coupling) between two or more disciplines (fields) of engineering. A piezoelectric analysis, for example, handles the interaction between the structural and electric fields: it solves for the voltage distribution due to applied displacements, or vice versa. Other examples of coupled-field analysis are thermal-stress analysis, thermal-electric analysis, and fluid-structure analysis.

Some of the applications in which coupled-field analysis may be required are pressure vessels (thermal-stress analysis), fluid flow constrictions (fluid-structure analysis), induction heating (magnetic-thermal analysis), ultrasonic transducers (piezoelectric analysis), and magnetic forming (magneto-structural analysis).

6.6.1. Methods

The procedure for a coupled-field analysis depends on which fields are being coupled, but two distinct methods can be identified - sequential and direct.

1. **Sequential Method**

The sequential method involves two or more sequential analyses, each belonging to a different field. One can couple the two fields by applying results from the first analysis as loads for the second analysis. An example of this is a sequential thermal-stress analysis where nodal temperatures from the thermal analysis are applied as "body force" loads in the subsequent stress analysis.

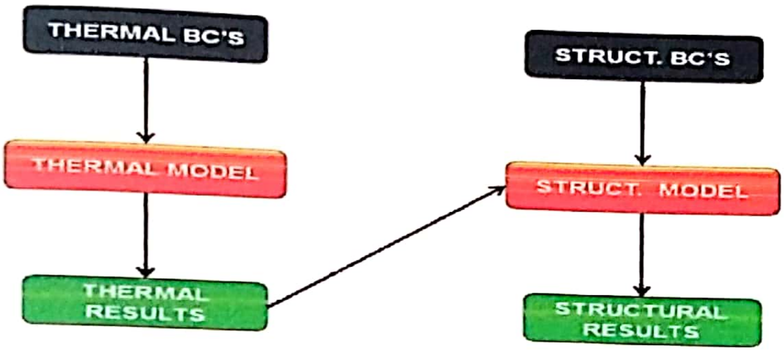


Fig 6.6 Flowchart of Sequential analysis

2. **Direct Method**

The direct method usually involves just one analysis that uses a coupled-field element type containing all necessary degrees of freedom. Coupling is handled by calculating element matrices or element load vectors that contain all necessary terms.

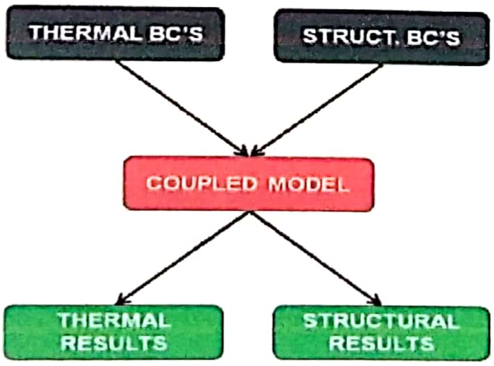


Fig 6.7 Flowchart of Direct analysis

For coupling situations which do not exhibit a high degree of non-linear interaction, the sequential method is more efficient because the two analyses can be performed independently of each other. In a sequential thermal-stress analysis, for example, a non-linear transient thermal analysis can be performed followed by a linear static stress analysis. The nodal temperatures can then be used for any load step or time point in the thermal analysis as loads for the stress analysis. Coupling may be recursive where iterations between the different physics is performed until the desired level of convergence is achieved.

Direct coupling is advantageous when the coupled-field interaction is highly nom-linear and is best solved in a single solution using a coupled formulation. Examples of direct coupling include piezoelectric analysis, conjugate heat transfer with fluid flow, and circuit-electromagnetic analysis

6.6.2 Types of Coupled-Field Analysis

- Thermal-structural
- Magneto-structural
- Electro-magnetic
- Electro-magnetic-thermal -structural
- Piezoelectric
- Thermal-pressure
- Velocity-thermal-pressure
- Pressure-structural(acoustic)
- Thermal-electric
- Magnetic-thermal

6.6.3. Thermal Structural Coupling

Thermal-stress analysis involves two sequential analyses

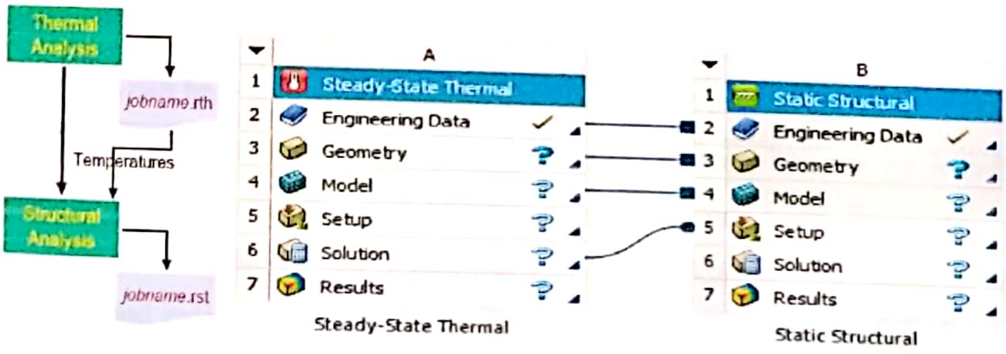


Fig 6.8 Thermal-Structural Coupling in ANSYS Workbench

I. Steady-State (Or Transient) Thermal Analysis

- Model with thermal elements
- Apply thermal loading
- Solve and review results

II. Static Structural Analysis

- Switch element types to structural
- Define structural material properties, including thermal expansion coefficient Apply structural loading, including temperatures from thermal analysis

6.7.Introduction to fatigue analysis in ansys:

It is estimated that 50-90% of structural failure is due to fatigue, thus there is a need for quality fatigue design tools. However, at this time a fatigue tool is not available which provides both flexibility and usefulness comparable to other types of analysis tools. This is why many designers and analysts use "in-house" fatigue programs which cost much time and money to develop. It is hoped that these designers and analysts, given a proper library of fatigue tools could quickly and accurately conduct a fatigue analysis suited to their needs. The focus of fatigue in ANSYS is to provide useful information to the design engineer when fatigue failure may be a concern. Fatigue results can have a convergence attached. A stress-life approach has been adopted for conducting a fatigue analysis. Several options such as accounting for mean stress and loading conditions are available.

Stress-life Data Options/Features

- Fatigue material data stored as tabular alternating stress vs. life points.
- The ability to define mean stress dependent or multiple r-ratio curves if the data is available.
- Options to have log-log, semi-log, or linear interpolation.
- Ability to graphically view the fatigue material data
- The fatigue data is saved in XML format along with the other static material data

Analysis

Fatigue results can be added before or after a stress solution has been performed. To create fatigue results, a fatigue tool must first be inserted in to the tree. This can be done through the solution toolbar or through context menus. The details view of the fatigue tool is used to define the various aspects of a fatigue analysis such as loading type, handling of mean stress effects and more. As seen in Figure 2, a graphical representation of the loading and mean stress effects is displayed when a fatigue tool is selected by the user. This can be very useful to help a novice understand the fatigue loading and possible effects of a mean stress.

Loading

Fatigue, by definition, is caused by changing the load on a component overtime. Thus, unlike the static stress safety tools, which perform calculations for a single stress, fatigue damage occurs when the stress at a point changes over time. ANSYS can perform fatigue calculations for either constant amplitude loading or proportional non-constant amplitude loading. A scale factor can be applied to the base loading if desired. This option, located under the "Loading" section in the details view, is useful to see the effects of different finite element load magnitudes without having to re-run the stress analysis.

- Constant amplitude, proportional loading
- Non-constant amplitude, proportional loading

Load Effects

Fatigue material tests are usually conducted in a uniaxial loading under a fixed or zero mean stress state. It is cost-prohibitive to conduct experiments that capture all mean stress, loading, and surface conditions. Thus, empirical relations are available if the fatigue data is not.

- Mean Stress correction
- Multi axial Stress Correction

Chapter 7

ANALYSIS RESULTS AND DISCUSSION

The Solid model is converted into a FEA model and the results are obtained after applying the structural boundary conditions. The loads and the constraints are imposed on this FEM model. The element used for analysis is 3-D 10-Node Tetrahedral Thermal Solid (solid 87). The model is fine meshed with 44898 elements and 82964 nodes. The stress analysis is carried at the cylinder head at compression ratio is 18.5.The results obtained from ANSYS are shown in figs The thermal result in form Max temperature and total Heat flux at different CR"s. The Structural results in the form of von-Mises stresses and deformations, Factor of safety are shown for all the critical angles at different CR's. These three results are further depicted under two conditions:

a) **Steady State Thermal Analysis**
b) **Static Structural Analysis**
c) **Fatigue analysis**

7.1 static structural analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS, Samcef, or ABAQUS solver. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

7.2 Steady state thermal analysis

Steady state thermal analysis consider the before structural analysis, in this analysis apply boundary conditions (heat transfer coefficient, heat flux) on the piston and we observe the maximum and minimum temperatures, total heat flux of piston

You can use a steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineers often perform a steady-state analysis before performing a structural thermal analysis.

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects or temperature dependent convection coefficient also makes the analysis nonlinear.

7.3 Fatigue analysis

Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of an intensity considerably below the normal strength. In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.

Material fatigue is a phenomenon where structures fail when subjected to a cyclic load. This type of structural damage occurs even when the experienced stress range is far below the static material strength. Fatigue is the most common source behind failures of mechanical structures.

There are three stages of fatigue fracture: initiation, propagation, and final rupture. Indeed, this is the way that most authors refer to fatigue fracture, for it helps to simplify a subject that can become exceedingly complex. Stage 1- Initiation.

- **Compression Ratios 18.5**

Apply the Boundary conditions on the cylinder head , we observe the results

The fixed supports are shown in detail in the figure and the pressure is applied at the inlet and outlet valves of the cylinder head

BOUNDARY CONDITIONS (STATIC STRUCTURAL ANALYSIS)

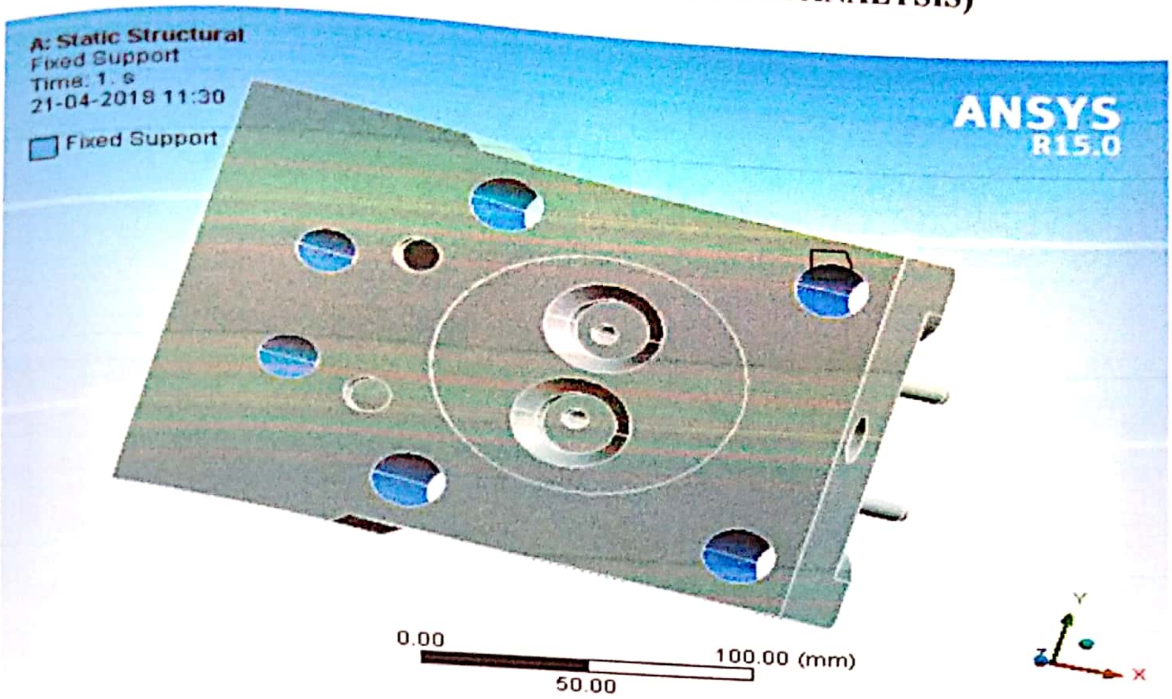

A: Static Structural
Fixed Support
Time: 1. s
21-04-2018 11:30
☐ Fixed Support

Fig. 7.1.1 boundary conditions(fixed points) in static structural analysis

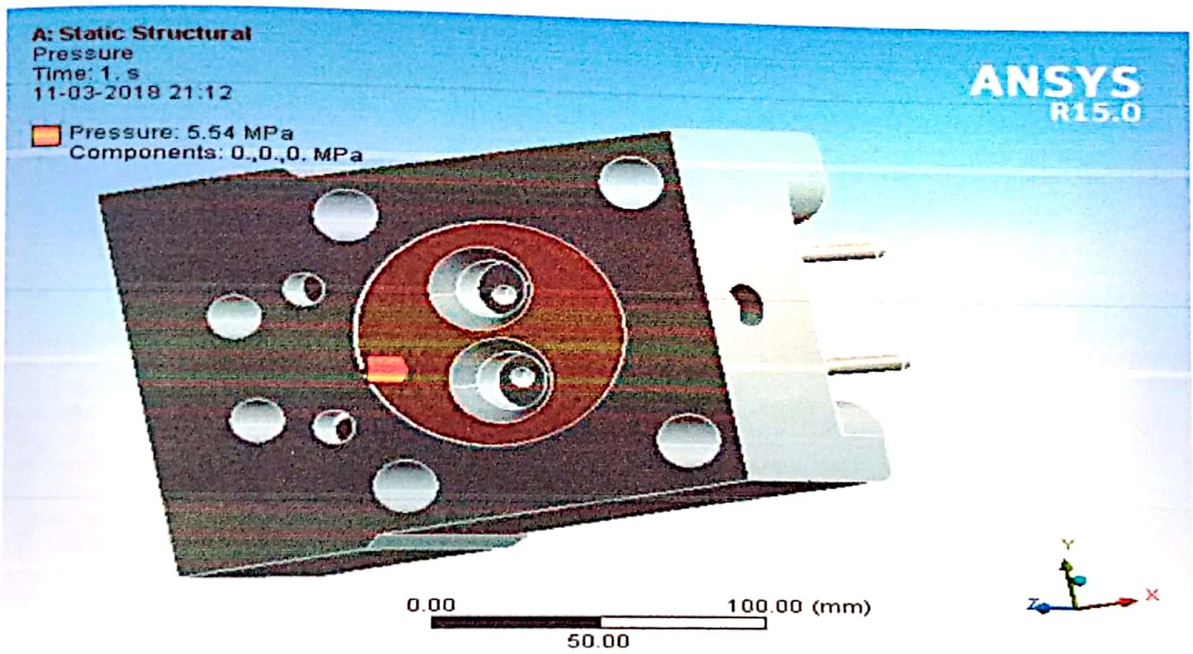

A: Static Structural
Pressure
Time: 1. s
11-03-2018 21:12
🟧 Pressure: 5.54 MPa
Components: 0.,0.,0. MPa

Fig 7.1.2 boundary conditions(pressure) in static structural analysis

VON-MISES STRESS

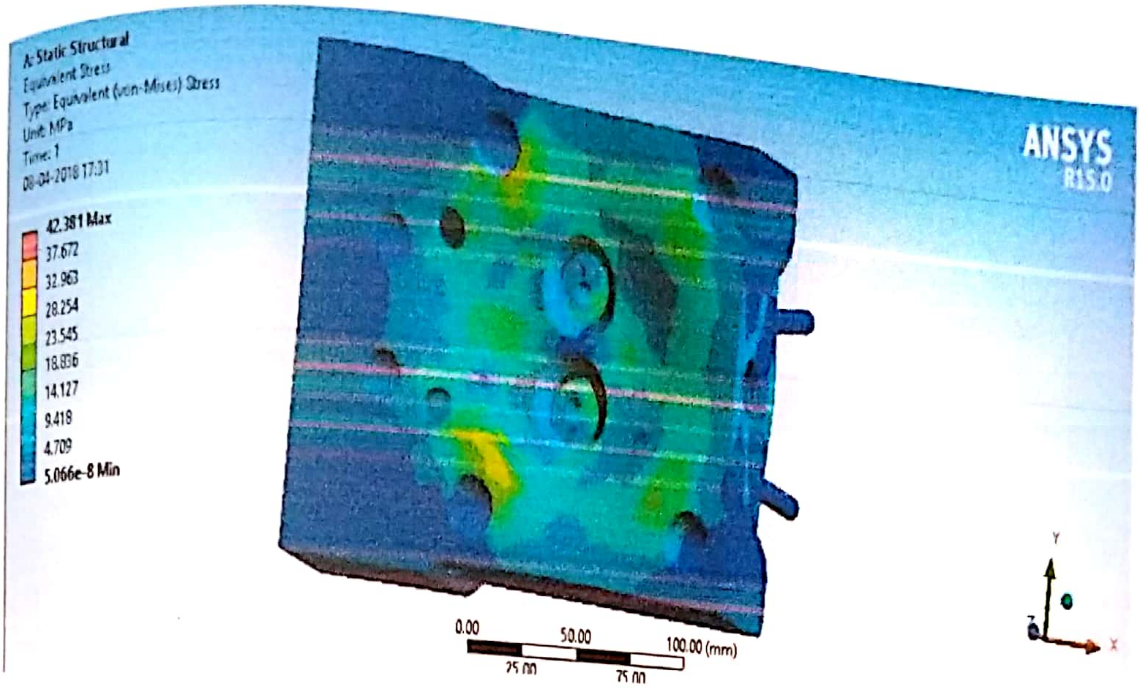


Fig 7.1.3 von-misses stress of cylinder head (aluminums A356-t6)

TOTAL DEFORMATION

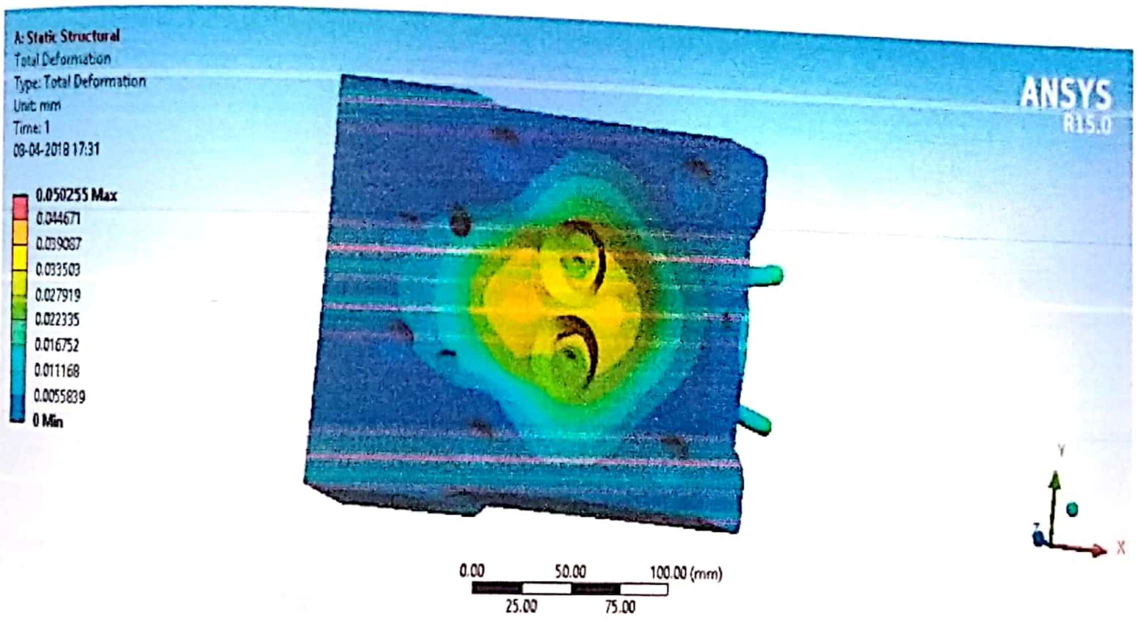
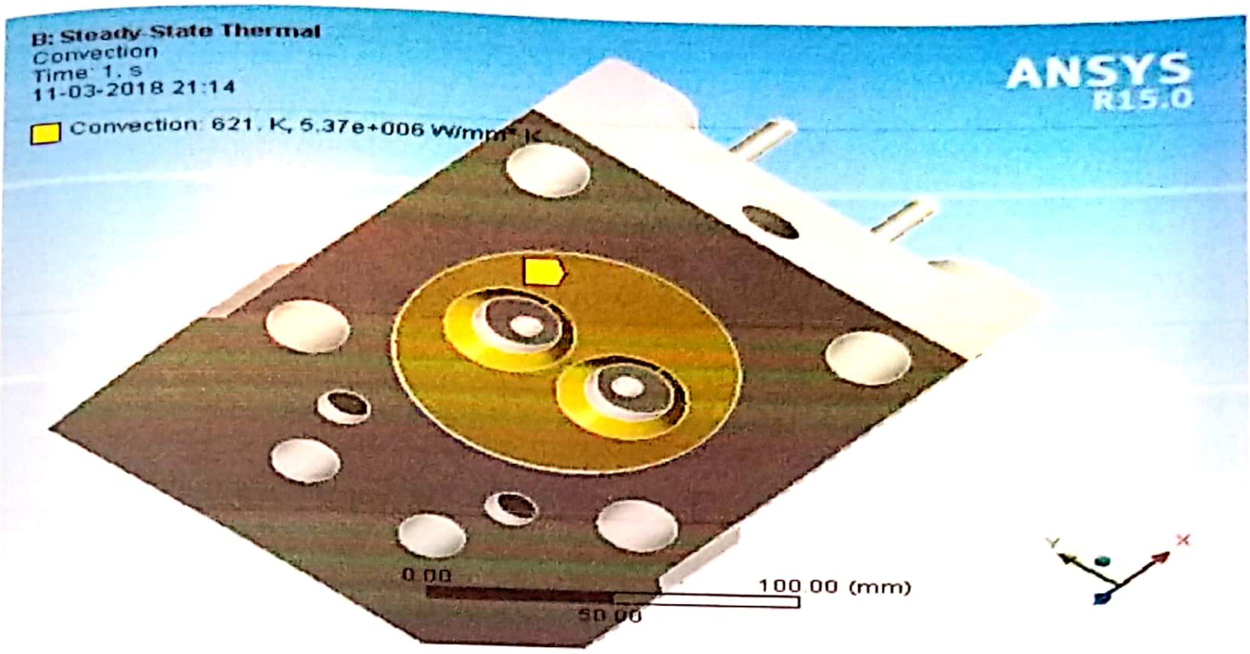


Fig 7.1.4 total deformation of cylinder head (aluminum A356-t6)

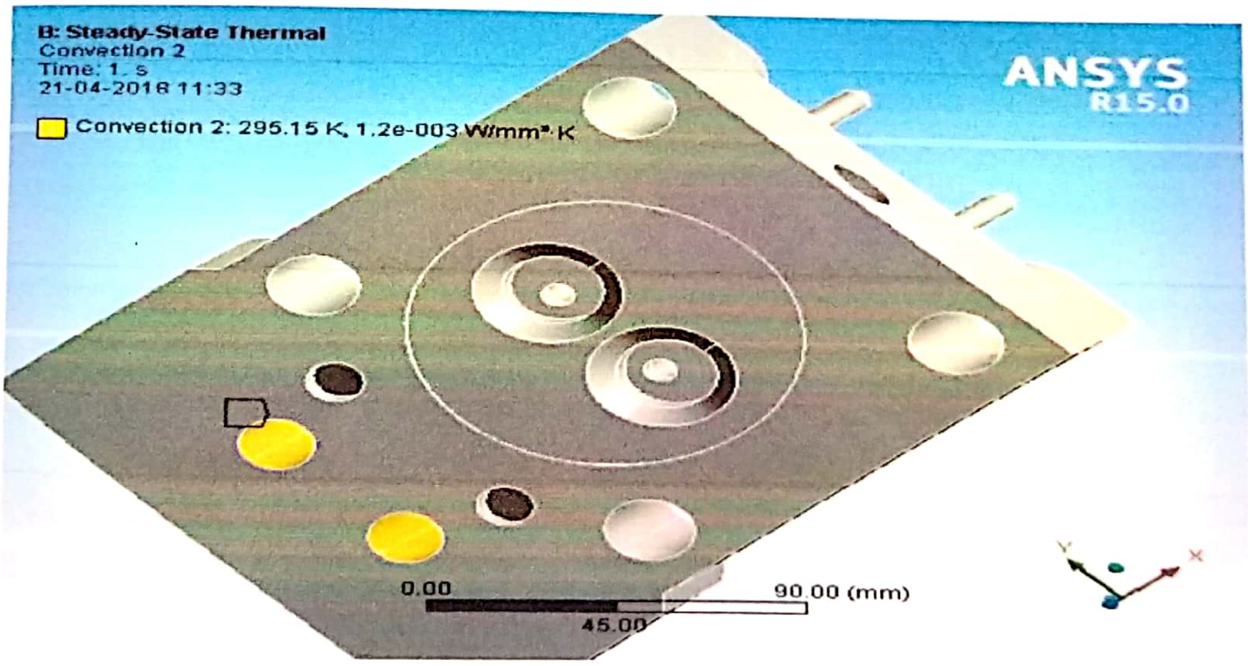
BOUNDARY CONDITIONS (STEADY STATE THERMAL)



B: Steady-State Thermal
Convection
Time: 1. s
11-03-2018 21:14

🟨 Convection: 621. K, 5.37e+006 W/mm²·K

Fig 7.2.1 boundary condition(conviction) in steady state thermal analysis.



B: Steady-State Thermal
Convection 2
Time: 1. s
21-04-2018 11:33

🟨 Convection 2: 295.15 K, 1.2e-003 W/mm²·K

Fig 7.2.2 boundary condition(conviction1) in steady state thermal analysis.

TEMPERATURE DISTRIBUTION

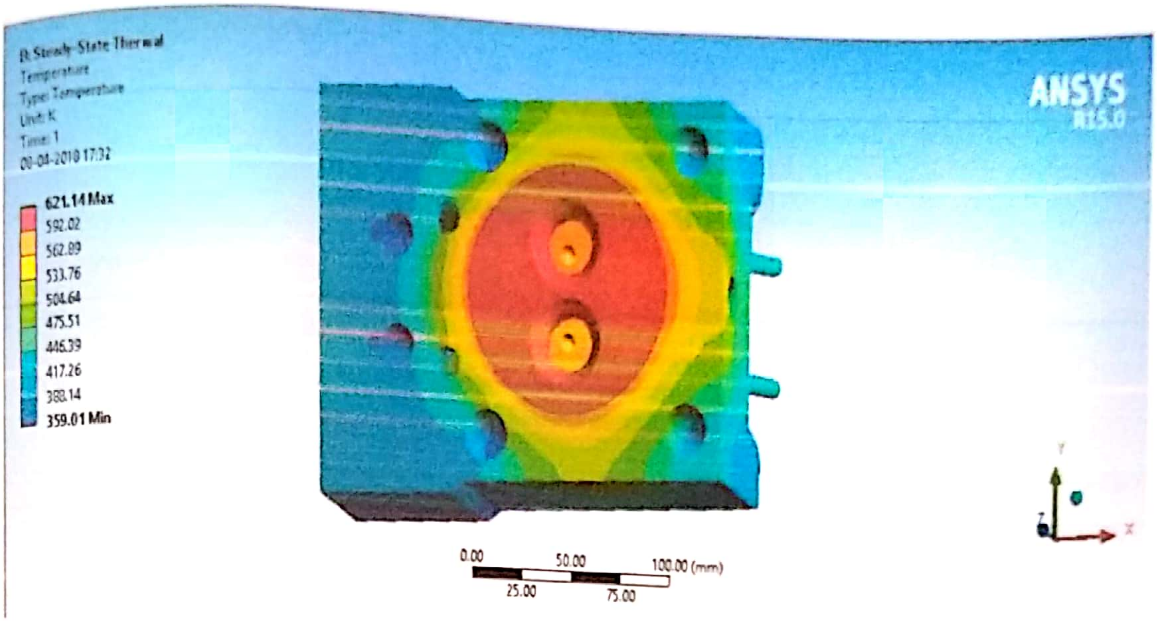


Fig 7.2.3 temperature distribution of cylinder head (aluminum A356-t6)

TOTAL HEAT FLUX

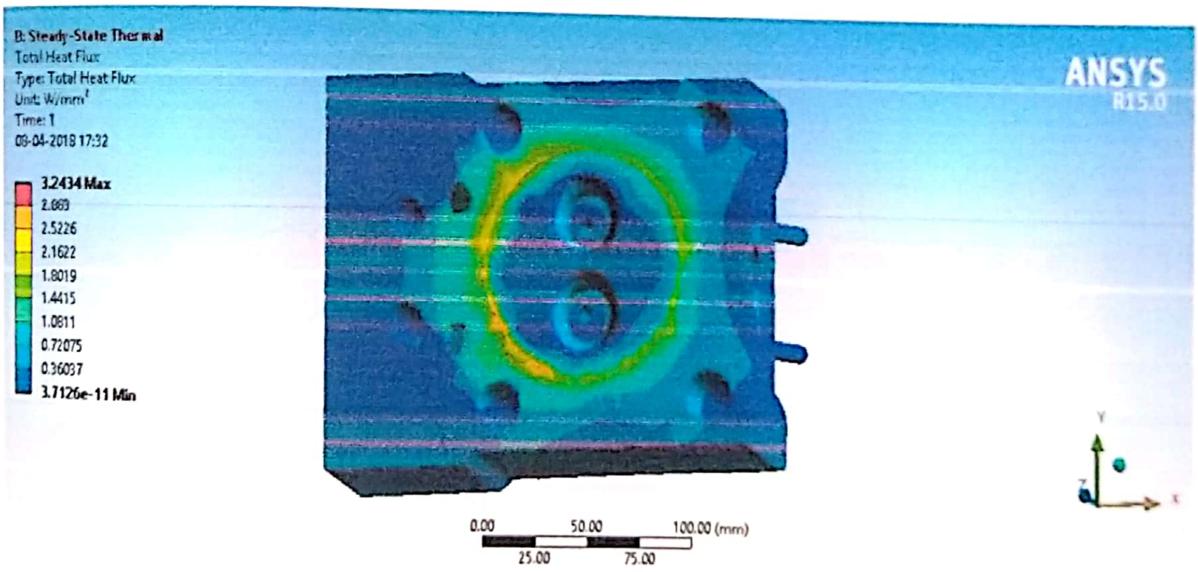


Fig 7.2.4 total heat flux of cylinder head (aluminum A356-t6)

FATIGUE –FOS

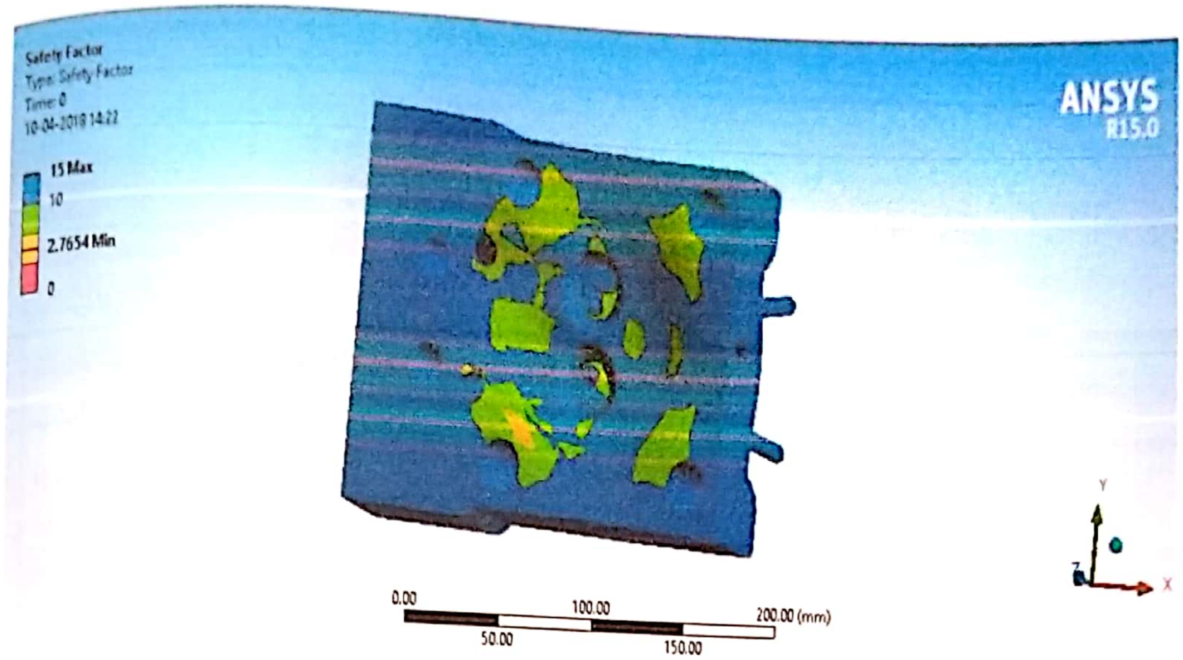


Fig 7.3.1 factor of safety of cylinder head (aluminum A356-t6)

FATIGUE – LIFE

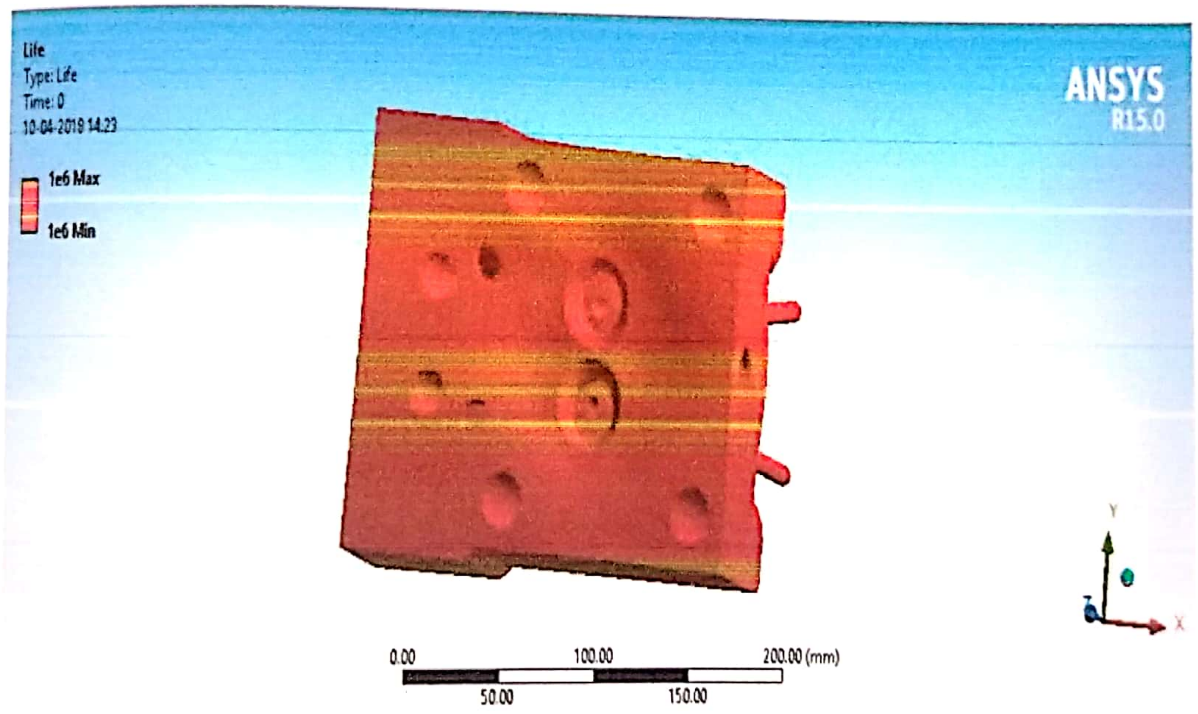


Fig 7.3.2 fatigue-life of cylinder head (aluminum A356-t6)

Table 7.1 five different materials of static structural and steady state thermal analysis results

Materials	**Total deformation (mm)**	**Equivalent Stress (von-misses) (mpa)**	**Temperature (k)**	**Total heat Flux (w/mm^2)**
Magnesium (AMC-SC1)	0.88871	75.608	621.31	3.1622
Gray cast iron (FG200)	0.019704	44.72	621.08	1.3674
Compacted Graphite Iron (CGI)	0.026031	77.3	621.07	1.5341
Aluminum alloy (319-T5)	0.048903	43.925	621.05	3.3817
Aluminum alloy (A356-T6)	0.050255	42.381	621.14	3.2434

Chapter 8

CONCLUSION

Experimental investigation is carried out on computerized VCR diesel test rig to determine the variation of pressure with crank angle in the cylinder at different compression ratios. The temperature variation of gases was further evaluated using the results obtained from the experimentation. Using this experimental observations and the actual dimension of cylinder head, stress analysis was carried out with the aid of the modern software CATIA and ANSYS. The stresses induced in cylinder head and deformations were found to be within allowable limits.

The stress analysis of the cylinder head was carried at five different materials of compression ratio 18.5. What they are CGI(GJV 450), GREY CAST IRON, A319-T5, A356-T6 and AMC-SC1. Through the analysis above five different materials aluminum alloy(a356-t6) gives better results.

The following inferences are drawn from the study.

1. The stresses induced in the cylinder head at compression ratios 18.5 is 42.381 Mpa.
2. Through the heat transfer analysis. it was observed that maximum temperature in the cylinder head occur at the compression ratio of 18.5 of value 348.14 ^{0} C
3. Further, factor of safety for fatigue analysis was determined as 2.7654 at compression ratio of 18.5 .

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