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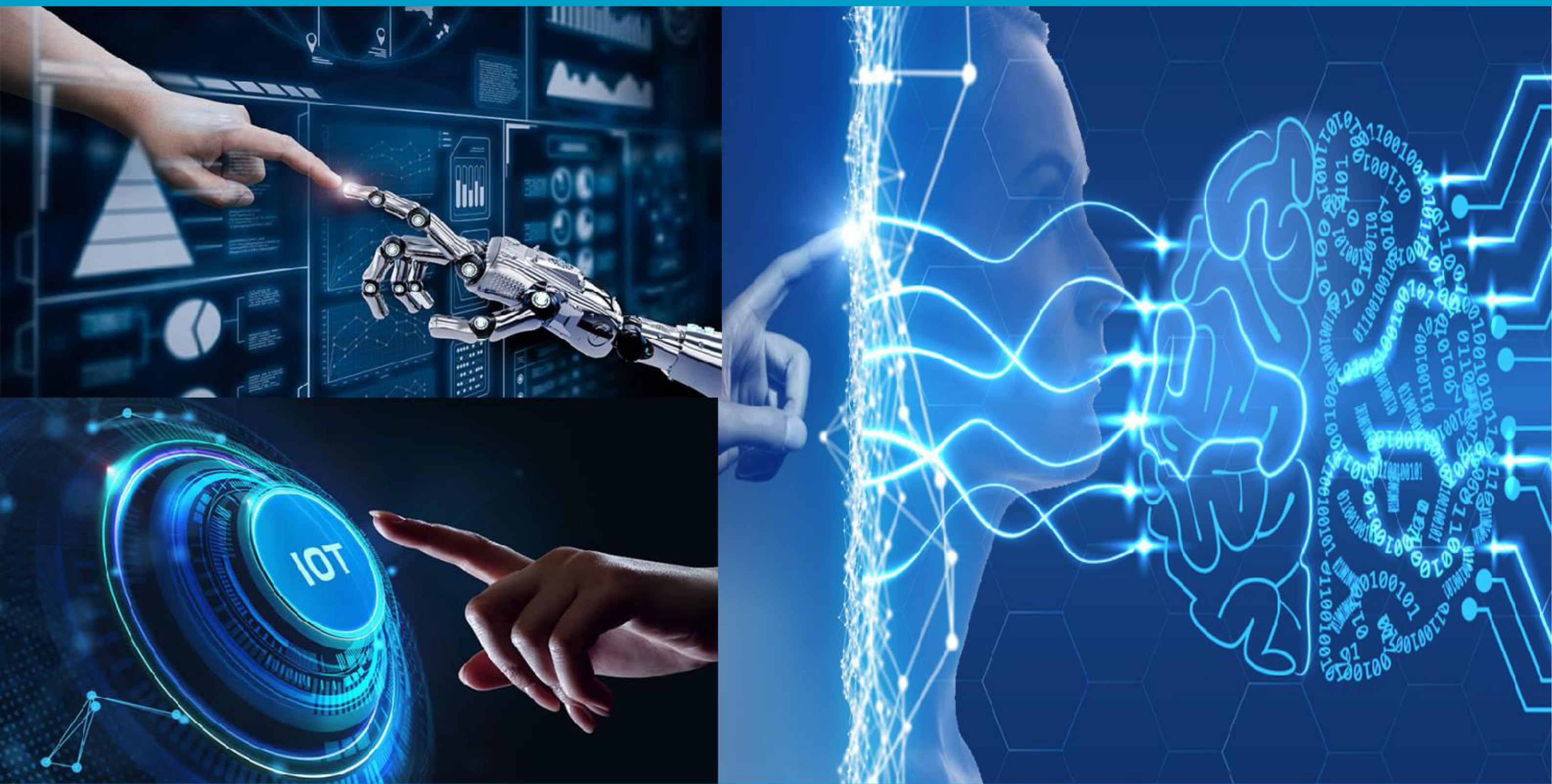


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# Thermal Investigation and Analysis of Stresses and Deformation of a Diesel Engine Piston using ANSYS Software

**Ranjan Kumar Singh, Ujjal Mukherjee, Vikash Yadav**

M. Tech. (Mechanical), B M Group of Institutions Farrukhnagar, Gurugram Haryana, India

Assistant Professor, Maharshi Dayanand University, Rohtak Haryana, India

Assistant Professor, Maharshi Dayanand University, Rohtak Haryana, India

**ABSTRACT:** This research offers a mechanical and thermal investigation using ANSYS software to analyse the stresses and deformation of a diesel engine piston under steady-state conditions. The simulation yields stress, strain, and temperature distribution inside the piston at the engine's usual operating state. The piston head and the region surrounding the gudgeon pin hole have the highest equivalent stress values, hence the risks of deformation are greatest in these areas. The greatest equivalent stress created by thermomechanical loading in this research is 216.5 MPa, which is extremely close to the yield strength of the aluminium alloy (315 MPa) utilised as piston material.

**KEYWORDS:** Thermal Mechanical Stresses; Deformation; Piston; ANSYS

## I. INTRODUCTION

Piston engines are the most common form of power generating in automobiles. The piston, which is an important component of the vehicle locomotive, is made up of an unoccupied container with grooves to accept the piston rings. The piston, once installed in the cylinder, creates an airtight chamber for combustion. One side of the piston is connected right before the connecting rod via a piston pin, while the other side burns petroleum. The piston transfers the linear reciprocating force generated during or after fuel combustion to assist the crankshaft in entering rotating motion. Furthermore, the piston functions as a moveable sealed connection to maintain the combustion safe in the engine cylinder. The piston material is subjected to severe mechanical and thermal strains as a result of high amplitude cyclic force, long-term high temperature, and insufficient cooling [1], [2]. Researchers have worked tirelessly to enhance piston design in order to obtain high engine performance. The works include, for example, a logical approach for calculating piston high temperature circulation [3] and modelling of the combustion flow [4], improvements in piston material characteristics to improve thermal and mechanical behaviour [5][6][7][8,] improvements in friction reduction and lubrication between the piston and wall [9],[10],[11][12][13][14], and advancements in modelling tools such as computer aided engineering and finite element methods [15][16]. During operation, the piston is subjected to high temperatures and high magnitude cyclic forces generated by fuel combustion. These harsh environmental conditions (high mechanical and thermal loads) are harmful to the piston and may lead to piston failure. Periodic changes in load and temperature cause cyclic stress and deformation in the piston, which leads to fatigue failure, a significant cause of piston damage. Much research has been conducted to determine the failure mechanism and strength of pistons. [17] [18] [19] Liuet.al. carried out numerical piston examination strong point of piston and buckle found in thermo-mechanical amalgamation intended for China-V -diesel locomotive in work [19] analyse the thermal hotness fields of temperature and thermal hotness stress below stable temperature meadow of diesel engine piston. Finite element analysis has become the main numerical approach for predicting the distribution of mechanical and thermal characteristics in most structural components in the age of modern computers. Liu analysed the mechanical and thermal state of the piston for a diesel engine and performed finite element analysis in the research [19], and [20] performed computer assisted engineering analysis on the piston to address a crack issue.

The result of a tired state. The author of study [21] investigated the fatigue life as well as the thermal stress in a piston. The study piston discovered that different types of coating on the outside surface minimise the greatest heat in the piston and also enhance the wear characteristics. [22] The thermal hotness of a ceramic-covered diesel engine piston was calculated using the 3-D finite component approach.

In this work, a 3D geometric model of a piston is generated using SOLIDWORKS software using the empirical formulae's derived dimensions and then imported into ANSYS workstation for further analysis. As boundary conditions, reference values for applied pressure, temperature, and heat flow were chosen. We derived mechanical and

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thermal stresses, equivalent stress, temperature profile fluctuation, heat flow, and equivalent elastic strain from simulation data. The purpose of this article is to demonstrate a road to excellence in the design of pistons for thermal and mechanical loads.

### 1.1 Design and modelling of piston

Piston material

The material for the piston is chosen based on the attributes needed by the piston in order for it to function and last longer. High thermal and mechanical strength to survive high temperature and pressure generated by fuel combustion, minimal mass to minimise inertia force for higher output and reduced noise against high amplitude vibration are some of the primary and critical qualities. To avoid fluid leakage from either side of the piston, the piston should also have an effective sealed moveable connection between the cylinder wall and the piston skirt. Also, piston wear should be kept to a minimum since it demands a large enough bearing surface.

### 1.2 PISTON

The piston is the 'heart' of a vehicle engine. The cylinder is the sole vital component in a vehicle, and it is carefully classified with machine execution, carbon exoneration, and the financial system. With the vehicle's greater speed and strength, its superior weight segment and higher force grow on a continuous basis. Because the working status of the cylinder is so bad, its reliability becomes a critical component in the enhancement of motor unwavering quality. The structure and function of cylinders are perplexing. In the workplace, the cylinders will supply pressure and twisting due to the intermittent burden effect caused by high gas pressure, high temperature, and fast reacting speed, as well as latency power, sidelong weight, contact, and so on. Consumption of the high weight air fuel mix generates high temperature, which causes the cylinder to expand, resulting in warm pressure and heated disfigurement within the cylinder. Warm twisting and mechanical distortion will result in cylinder breakage, convolution, and other effects. In this regard, it is critical to disassemble the pressure field, temperature field, heat move, warm burden, and mechanical burden coupling of the cylinder in order to reduce the warmth load and improve the warm pressure dispersion and working dependability during the cylinder plan. The investigation methodology for the restricted component yields a groundbreaking estimate apparatus that outperforms the test strategy and hypothesis examination technique and has become a substantial way for studying inward burning motor execution. A cylinder's capacity is to withstand high gas pressure while turning the driving rod via the cylinder pin. Cylinder operates under high temperature, heavy oil, rapid and hopeless circumstances. Cylinder makes direct contact with high-temperature gas; during fuel combustion, the quick temperature can reach 2500K. When the cylinder is operating in the motor, the hotness of the top portion of the cylinder may be achieved to 8001000k due to the unusually high hotness and the lacking hotness down scenario. Furthermore, temperature distribution is uneven. The gas pressure, especially the work pressure, is carried by the cylinder's head. The gas motor has a maximum pressure of 35Mpa and the diesel motor has a maximum pressure of 69%. The cylinder responds at a quick (812m/s) rate, and the speed changes, creating a large inertial force that causes the cylinder to endure an astounding additional weight. Working in these dreadful circumstances accelerates cylinder wear, resulting in increased weight, heated pressure, and gas substance degradation.

## II. RECONSIDERATION OF LITERATURE

A survey of writing is reported while keeping the project's scope and goals in mind. As a result, a variety of research on piston design, piston modelling, and piston thermal and mechanical stress analysis are provided here.

It aimed to reduce the force of hot and fundamental concerns by using the artistic material Silicon Nitride as the material for the cylinder crown (the top bit of the piston).

Because the crown material is weak and the skirt material is flexible. A clay reinforced fibre strip was offered in the midst of the earthenware crown and Al composite skirt to keep a strategic distance from the disappointment of the fired crown due to its brittle nature when exposed to influence stacks that are aftereffects of the blast of ignition gases. The cylinder material in this study was Eutectic Al Alloy (Si 11-13%). Initially, a warm and basic study was done on an Al Alloy cylinder without a silicon nitride diadem and then with a silicon nitride diadem using the software ANSYS. At that stage, the results obtained are considered. The analysis of data revealed that the cylinder orchestrated by silicon nitride diadem is wiser to withstand high warm and auxiliary uncertainties than the cylinder orchestrated by silicon nitride crown.

Ajay Raj Singh [2] used a restricted component method to represent the basic and warm pressure appropriation of three different aluminium amalgams of cylinder (FEM). M.X. Calbureanu [3] investigated the behaviour of an ignition motor

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cylinder built of aluminium alloys. The report illustrates the job progress by employing a restricted component research approach to predict greater pressure and basic area on the part.

S.S. Feng [4] presented a thermodynamic model of an IC motor with ignition analysis. The model is illuminated by a heat discharge job and an accurate transformation proficiency factor. The weight results obtained by describing the thermodynamic model are compared, as are the predicted pressure data for a fully instrumented research facility IC instant start (SI) motor. Scaling limitations for duration to peak weight, top weight, and most severe rate of weight ascension (among others) are established and compared, as are numerical replicas.

Venkata Rajam et al. [5] improved the cylinder by making it lighter and more grounded, as well as covering it with zirconium. The covered cylinder underwent a Von misses test using ANSYS for consignment functioning on the zenith. Examine the force distribution on various parts of the covered cylinder to assess the concerns caused by air weight and temperature variations. After augmentation, von-misses pressure was increased by approximately 16%, and redirection was increased.

E. H. Smith et al. [6] investigated and considered the effects of several factors such as amount of bore twisting, ring similarity, ring hub movement, and circumferential diversity of the ring face profile. An enhanced method for determining oil accessibility in a ring pack was also developed by taking into account the influence of relative positions of rings on the cylinder and oil collecting before the ring. The model's improvement is also summarised and some selected outcomes are shown.

At some point throughout the examination of a genuine four fondle engine chamber, RadoslavPlamenovGeorgiev et al. [7] observed the collision of diadem thickness, container width, and compartment zenith land stature on force transfer and hard and fast twisting. The whole update is based on verifiable examination. The FEA evaluation is completed with the assistance of ANSYS for precise geometry. Using limited segment methods, this broadsheet delineates the weight dispersion and warm issues of three different aluminium come together chambers. The constraints employed for fun include operating air weight, temperature, and compartment material holdings.

MuhammetCerit [8] determined the high temperature and force circulations in a partially earthenware encased sparkle set off (SI) vehicle cylinder. The effects of wrapper width and breadth on hotness and nerve tension appropriations were investigated, as well as correlations with grades on or after an uncoated container. It can be observed that the covering exterior temperature increased by increasing the thickness in a decreasing velocity outside temperature of the cylinder by 0.41 mm covering width was increased up to 81.9 °C. The average weight on the covered exterior decreases by covering width up to about 1 mm, for which the stress calculation is the pedestal. However, it increases when the casing thickness exceeds 1.1 mm. The commonest force drops regularly and the most extreme cut off force grows at a degrading rate among the external protection respect cover escalating covering width was observed as close to 1 mm under the supplied environment.

G. Floweday et al. [9] designed a modified test to analyse the impact of different types of fuel on the strength of the oil structural section in passenger car diesel engines. Several unexpected chamber head, turbocharger, and cylinder disappointments occurred throughout the test programme. This investigation focused on the cause of the cylinder disappointments seen throughout these tests. Investigations of the broken cylinders indicated that thermo-mechanical overtiredness initiation occurred as a result of the essential silicon period divide and subsequent miniaturised scale break expansion as a result of the thermo-mechanical mountain exceeding the top limit. The investigation further revealed that the abnormal thermo-mechanical cylinder stacking was caused by over-fueling and a combination of increased and improperly managed post intercooler air temperature. There was no evidence to suggest that the disappointments were linked to the test fuel specifications.

## III. PISTON REPRESENTATION AND DESIGN

### 3.1 PISTON MATERIAL

Pistons should have high commonality to tolerate large gas weight and inactivity powers, while having the least bulk to restrict idleness control. The cylinder should be designed in such a way that it can disperse the kindness of ignition quickly and with little agitation, while also being sufficiently rigid to bear heated and mechanical twisting. To prevent excessive wear and mechanical mutilation, the cylinder should form a forceful gas and oil fixing of the chamber and provide appropriate bearing zone.

The primary material used for cylinders is aluminium compound. Aluminum cylinders might be frightened or manufactured. Cylinders are also made of cast iron. Cast iron was a popular material for cylinders in the early days because of its excellent wear properties, coefficient of extension, and overall suitability. In any case, owing of the reduction in weight in responsive components, the use of aluminium for the cylinder was essential. A greater thickness

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of metal is required to achieve comparable quality. Regardless, a part of the advantage of the light metal is lost. Aluminum is a poor substitute for cast iron in superiority and wear description, and its higher coefficient of expansion necessitates more significant leeway in the chamber to keep a strategic distance from the risk of seizing. The warmth conductivity of aluminium is roughly threefold that of cast iron, and this, combined with the greater thickness fundamental for quality and enables aluminium combination cylinder to have at a much lower fever than a cast iron one (200 °C to 250 °C when contrasted with 400 °C to 450 °C), thus carbonised oil doesn't frame on the underside of the cylinder, and the wrench case stays cleaner. Aluminum's cool flowing quality is now regarded as as important as its softness. To be sure, cylinders are sometimes manufactured thicker than would typically be desirable for quality in order to provide better cooling.
The cast iron cylinder is suitable for use in water, and the speed of the motor cylinder is less than 6 m/s. The combination of aluminium cylinders is mostly used for Evaluated intensively motor operating at higher higher speed. Because aluminium compounds are mostly used for Hi hotness cylindrical conductivity of cast iron, in the approach of cylinder. Because of the high rate of disturbance caused by the high temperature, it maintains the highest temperature between the middle borders of the cylinder head.

### 3.2 IC engine piston mechanism must have the subsequentdescription:

- Tensile, compressive, and bending strength to reject gas forces
- least quantity/light load
- capable of giving in return with the least amount of noise/vibration
- have enough comportment neighbourhood to put off wear
- Must adhere the gas starting top and oil on or after the foundation.
- Must dissolve the heat generated during cremation.
- high-quality deformation combat under significant stresses and high heat.

Given the cylinder requirement stated above, the material used in this investigation is Al 4032.

**Table 1: Composition of Al 4032[*] is given below:**

| | |
|---|---|
| Aluminium | 84.9% |
| Silicon | 11.93% |
| Magnesium | 0.99% |
| Copper | 0.92% |
| Nickel | 0.91% |

**Table 2: Physical properties of Al 4032[*]:**

| PROPERTIES | Assessment |
|---|---|
| **(Gpa),** Modulus of elasticity | 79 |
| **(MPa)** UTS | 381 |
| **(MPa),** YTS, | 316 |
| **(W/mK),** Thermal conductivity, | 156 |
| Poisson’s ratio | 0.34 |
| Density, g/cc | 2.69 |
| Thermal expansion coefficient, $/^{0}C$ | $19.4\times10^{-6}$ |
| Specific heat capacity, J/kgK | 870 |

## IV. THERMAL AND MECHANICALANALYSIS OF PISTON

### 4.1Computer Aided Engineering

The word procedure recreation refers to any strategy in which at least one of the process limits of a genuine physical procedure or procedure family is or is expected to be present before its or their actual occurrence. If metal occurrence occurs in framing forms, the point of assurance of these limits is normally at least one of the accompanying:

- Examining the feasibility of the technique structure for producing a workpiece,
- Assessing the item's attributes for administrative usage
- Increasing understanding of the actual technique in order to enhance the production grouping.

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As a result, the use of process recreation must always be more careful than the usage of the actual method. The business programmes, which are substantially restricted component programmes, have such pleasant pre- and post-processors that any understudy or architect may use the projects. Regardless, efficient use of these virtual items necessitates

1. The existence of a well defined physical problem for which a numerical evaluation may provide a solution
2. The appropriate regard for this bodily problem (improvements, presumptions, identification of administering physical marvels),
3. The appropriate spatial discretization of the romanticised problem (kind of components, geography of component work, thickness of component work)
4. The establishment of appropriate restriction conditions

5. The application of appropriate material rules and limits
6. The selection of appropriate numerical boundaries (punishment factors, union cutoff points, increase sizes, remeshing model),
7. Effective investigation (sensible computational occasions, sensible demonstrating times, sensible capacity prerequisites),
8. Accurate numerical results translation

**4.3 Pistonstructural Investigation**

Throughout the control stroke, the burning air in the ignition machine compartment exerts force to the top of the cylinder. The weight power would be used as a limit condition in the fundamental study of the cylinder using ANSYS15 taskbench. Predetermined assistance has been defined on the pin space surface. Since the cylinder would shift from TDC to BDC and it would aid with fixed help at stick opening. So, whatever the heap is proper on cylinder because of air blast that power foundation to cylinder stick dissatisfaction (initiating twisting burdens). During the force stroke, the most severe weight following up on the cylinder is 6 MPa [@].

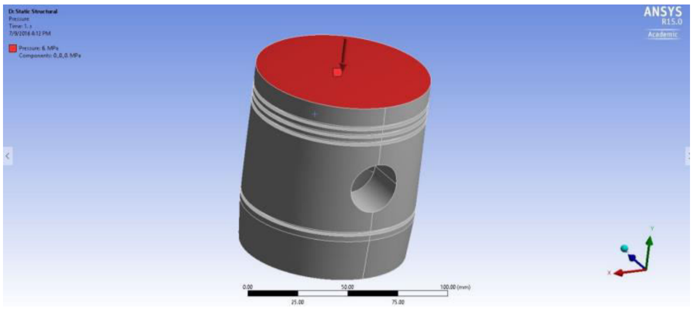


**Fig. 1:**Applied pressure with fixed support

Following the application of a particular pressure to the piston in the ANSYS workbench 15.0 simulation of the model, different simulation results are achieved, resulting in a piston structural examination.
The grades achieved from the piston structural studies are as follows:

1. Stress equivalent.
2. The highest primary stress.
3. Complete deformation

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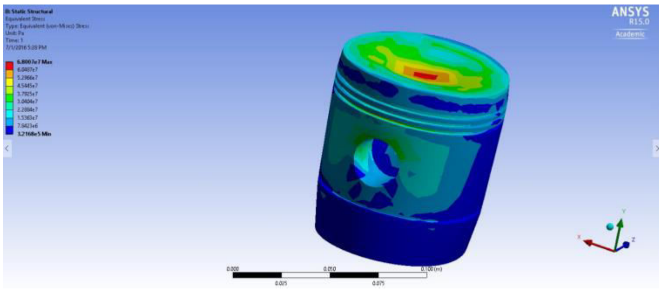

**Fig. 2:**outline plot ofcorresponding (Von-mises) tension in piston

The most severe assessment of proportional concern in the cylinder during the auxiliary examination is near the middle of the cylinder head, as shown in Fig.2. The greatest severe similar pressure is estimated to be 68 MPa. The estimate of equal pressure at the skirt of the cylinder is very low, as shown in the figure, but proportionate concern in the district of the cylinder pin is rather large as compared to other parts of the cylinder skirt.

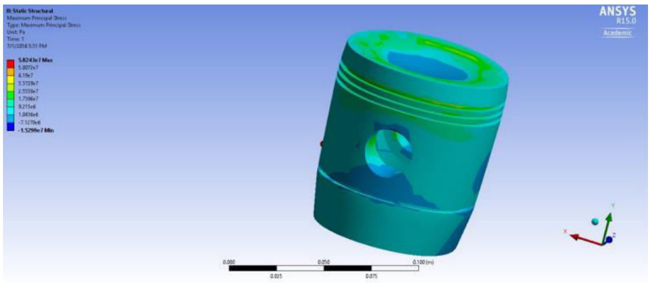

**Fig.3:** outlinedesign of Maximum principal constant worry in piston

Figure 3 depicts the cylinder's most severe principal pressure circulation. The most severe estimate of primary pressure is 33 MPa, which is mostly near the cylinder's commencement. Furthermore, the most extreme chief force estimate is much lower in the cylinder skirt region. Estimation of maximum chief pressure is also greater in the vicinity of the scores of the rings' extent, which lay in the range of 25-35 MPa.

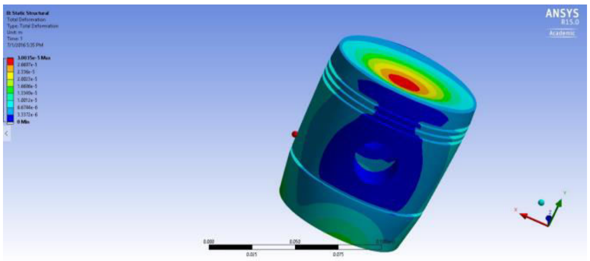

**Fig.4:**pistonoutlinedesign of completeDeformation.

During the auxiliary investigation of the cylinder, Fig.4 reveals that the highest distortion in the cylinder occurs near the middle of the cylinder head. In comparison to the deformation of the cylinder head, the full deformity in the other area of the cylinder is less. The cylinder's skirt experiences the least twisting. In the cylinder pin area, distortions near the midsection of the skirt are consistent and most acute.

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### 4.6 PARAMETERS CONFIRMATION BY USED IN THE DESIGN OF PISTON

**Measurement of exhaust temperature of the above Engine with the help of thermal imagine camera:**

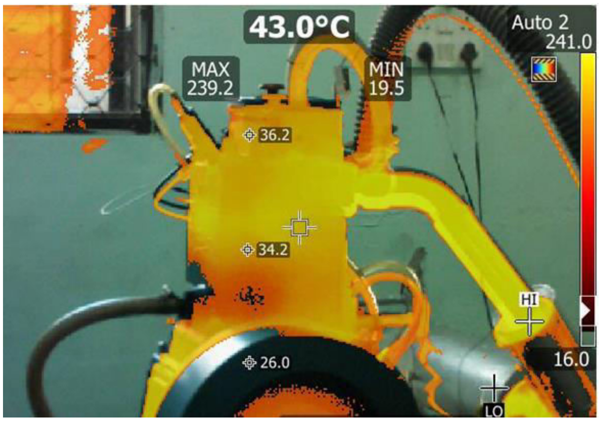
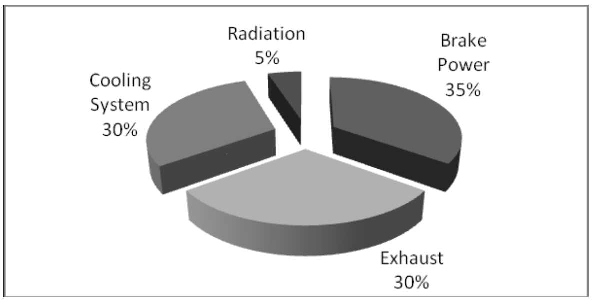



**Fig. 5:** Design of Piston

The highest temperature indicated by the thermal image in the frame was 239.2 0C at the engine's exhaust outlet pipe. And the outside temperature is 26 degrees Celsius.

During the operation of the IC machine, a large amount of energy is lost to coolant and in the form of exhaust energy [&], as seen in fig. 5 -.




According to fig.-, around 30% of total energy is lost to the environment through engine exhaust. At first, the enthalpy in the fume's gases may be partitioned into the following components:
60 percent reasonable enthalpy
Motor liveliness of fumes: 7%
20% insufficient ignition phrase
Warmth transfer to the fume's framework: 12% (some portion of which is transmitted to the earth)
A significant portion of the fumes vitality is plainly transported to the surroundings via a reasonable sort of warmth move, which may be evaluated by determining the fumes gas temperature.
We discovered the temperature at the fumes outline temperature when estimating the casing temperature of the IC motor, which must be significantly closer to the temperature of the fume's gas.
Along these lines, the fumes gas temperature = 245 0C. (which is marginally higher than the edge temperature at the fumes).

**TABLE3: Specification of Engine:**

| | |
|---|---|
| Number of strokes | 4 |
| Number of cylinders | 1 |
| Cycle of engine | Diesel |
| Cylinder diameter | 88 |

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| | |
|---|---|
| Stroke length | 110.0 |
| Compression proportion | 17.51:1 |
| Rated- power | 5.21 |
| Rotation, RPM | 1500 |
| Swept volume, cc | 661 |
| Specific fuel consumption, kg/kW-hr | 0.22 |
| Cooling system | Water cooled |

**Warmth misfortune during the exhaust gas commencing interior burning is determined seeing thatfollow:**
Accepting
Vol productivity ($\eta v$) is 0.89
Thickness diesel petroleum is 0.84 gm/cc
high in calories estimation of diesel is 42 MJ/kg
Thickness intuition fuel is 1.1617 kg/m3
Explicit warmth of fumes air is 1.1-1.25 KJ/kg

Pressure proportion (Vr) = (Vc + Vs)/Vc

17.5= (Vc+6.61×10-4)/Vc

In the Vc= 4×10-5 m3

All out volume = Vc + Vs = 7×10-4 m^3.

Explicit fuel utilization = mf/power

Mass of fuel (mf) = s.f.c × power

mf = 220×5.2 = 0.317762 gm/sec

Vol rate = cleared vol × speed.

In V = Vs × N = 8.361×10^3 m3/s.

Volumetric proficiency ($\eta v$) = mass stream pace of air/(thickness × rpm × cleared volume)

mama = 0.9×1.16×750×6.61×10-4 gm/sec

Mass stream pace of fumes gas (me) = mf + mama = 8.9427×10-3 gm/sec

Henceforth reasonable warmth misfortune to deplete (Qe) = me × cp × ΔT.

Qe = 8.9427 × 1.1 × (245-26)

Qe = 2.154 Kw....................................................... (10)

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In the event that 35% of the all out vitality is changed over to the brake intensity of the motor which is 5.2 kW, in this way the estimation of all out vitality created in the motor = 5.2/0.35 kW

Henceforth all out vitality created in the motor =14.85 kW

Complete vitality squandered in exhaust = 14.85× 0.3 = 4.255 kW

Out of the complete fumes vitality 60% is as reasonable vitality,

Henceforth reasonable vitality misfortune in exhaust = 0.6 × 4.255 = 2.553 kW

The estimate of acceptable vitality loss in fumes obtained theoretically is very close to the estimation of reasonable vitality loss in fumes obtained by explanatory strategy (10) for the specified four strokes Diesel Engine. In this way, we may apply the limit conditions indicated in the references [&] and [@].

## V. RESULTS AND CONCLUSION

The following data were obtained during the thermo-mechanical investigation of a piston made of aluminium alloy:

1. The largest importance of corresponding or von-mises pressure acquired at the piston top in the mechanical study of the piston is 68 MPa. Other components of the piston have have equal stress assessments.
2. Maximum overall deformation occurs at the piston head due to mechanical loading, with a maximum value of 0.03 mm.
3. Thermal analysis of the piston reveals a difference in the temperature contour at the piston, with a maximum temperature of magnitude 300 0C at the piston's starting and a minimum temperature of 48.5 0C at the piston's skirt.
4. A maximum thermal strain of 0.0011 was measured at the piston head, with a value decreasing towards the piston skirt to a minimum of 9.1110-5.
5. The overall high temperature flux obtained in the grooves of the first compression ring has a value of 1.6155106 W/m2. Another greater heat flux measurement is achieved in other grooves of the rings and at the piston head, with a magnitude of 0.9105 W/m2.
6. When both thermal and mechanical loading operate on the piston, the maximum value of equivalent pressure occurs, which is 216.5 (MPa), and an assessment is reached near the hole of the gudgeon pin.
7. The maximum overall deformation in the thermomechanical loading occurs above the piston starting border and has a value of 0.052 mm.
8. 0.003049 is the maximum equivalent elastic strain obtained around the hole of the gudgeon pin.
9. In a heated inquiry of the cylinder, the temperature profile at the cylinder is varied, with the most extreme temperature of approximately 300 0C occurring at the cylinder head and the lowest temperature of 48.5 0C occurring at the cylinder skirt.
10. A maximum thermal strain of 0.0011 was measured at the piston head, with a value decreasing towards the piston skirt to a minimum of 9.1110-5.
11. Total heat flow reached its peak in the grooves of the first compression ring, reaching 1.6155106 W/m2. Another greater heat flux measurement is achieved in other grooves of the rings and at the piston head, with a magnitude of 0.9105 W/m2.
12. When both thermal and mechanical loading operate on the piston, the highest value of equivalent pressure achieved is (216.5 MPa), and this assessment is attained near the hole of the gudgeon pin.

The piston head and the region around the gugeon pin hole have the highest equivalent stress values, hence the risks of deformation are greatest in these areas. The greatest equivalent stress created due to thermo-mechanical loading in this research is 216.5 MPa, which is extremely close to the yield strength of the aluminium alloy (315 MPa) utilised as piston material.

1. In this work, only the static FEA of the cylinder was conducted using the product ANSYS. This study may be extended to include the effect of loads on the cylinder under certain situations.

2. Exploratory pressure analysis (ESA) may also be used to identify fears, which will offer further reasons to examine the modified attributes obtained.

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3. This study may be extended to include other types of aluminium compounds as cylinder materials, such as cast aluminium, produced aluminium, cast steel, and made steel.

4. Aluminium compounds may be coated with aluminium oxides for use in high-temperature cylinders.

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+91 99405 72462 +91 63819 07438 ijmrsetm@gmail.com