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Using Finite Element Analysis, the Design, Structural, and Thermal Analysis of a Piston

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Abstract:

There is a certain piston design and its maximum gas pressure that was selected for this project. CATIA V5 solid modelling software will be used to produce a piston model for this project. ANSYS will be used to mesh and analyse the geometry. In order to examine piston input conditions and the analysis method, a comprehensive literature search was done. The crucial region of the piston is subjected to significant stresses while operating at high combustion gas pressures, which act as mechanical loads. A thorough static structural analysis is performed for a variety of loading conditions, such as the maximum gas pressure load. A comparison study is carried out in order to choose the best material. Material is never dominated by a comparative analysis. Pneumatic chambers, for example, use cylinders as mechanical components. Gas blowers, syphons, and motors that react. A cylinder seals up the upward movement inside a chamber, preventing any air from leaking out. The cylinder is a critical component of the engine and is subjected to significant mechanical and thermal stress in the automobile industry. Because the cylinder crown and cooling displays have such a large temperature difference, warm loads are begun in the cylinder. They are made of aluminium because of its low weight and heat conductivity. However, it is not recommended for use in high-temperature applications because to its poor hot strength and high development coefficient. To transfer power from the expanding gas to the barrel-shaped shaft, an interfacing bar and an extra segment pole are used in a motor's section bar or associating bar. For packing or removing liquid stored in chamber, syphons revolve around cylinder capacity and transmit power from driving rod to it. In the first stage, this investigation focuses on the main study of a standard cylinder made from aluminium composite. The next step is to focus research on an aluminium and cast iron cylinder. The third level of piston development should use lightweight, low-cost, and thermally safe materials. Verification of research findings by comparing them to more conventional sources

INTRODUCTION

The piston is a critical part of mechanical engineering because of its many applications. An internal combustion engine, a pneumatic cylinder, a hydraulic cylinder are all examples of mechanical systems that use pistons. Reciprocating pumps, gas compressors, pneumatic cylinders, and reciprocating engines all use pistons as mechanical components. Piston rings are used to keep the moving part of a cylinder gastight, and they are used with a piston. An important part of a motor's crankshaft is the piston rod and/or rod connector, which transfers force from rising gas in the cylinder to the crankshaft. As a result of the piston's form and exposure to structural and thermal stresses, a research is necessary. Pneumatic and reciprocating engines, pumps, compressors, and gas compressors all use pistons as moving parts. In an internal combustion (IC) engine, pressure from the expanding combustion gas in the combustion chamber acts on the piston-connecting rod assembly, which in turn transmits motion to the crankshaft. To improve engine performance, one method is to change the material of a component inside the combustion

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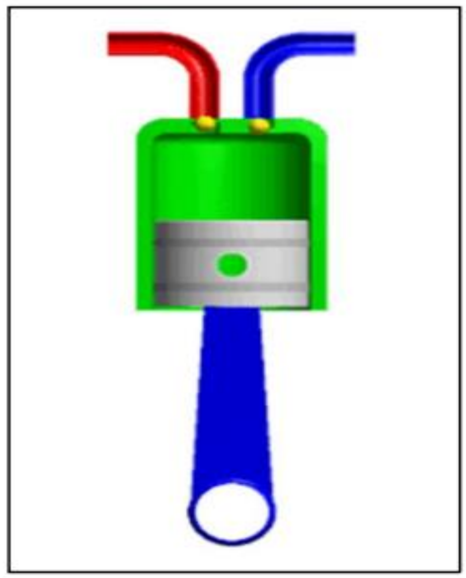
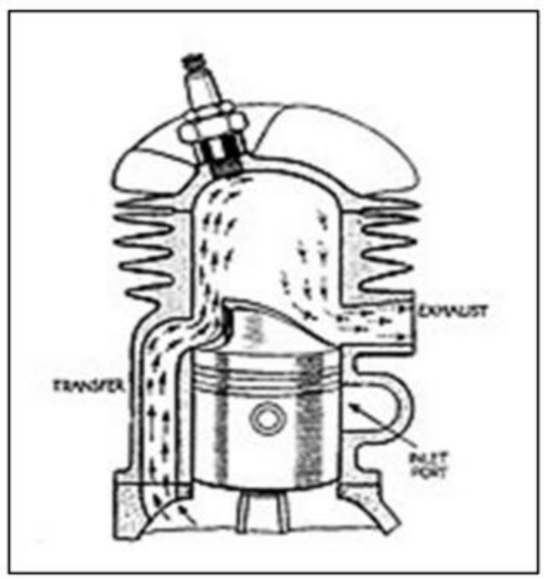
chamber. This is one of the solutions. Engine performance may also be improved by altering the component shapes and sizes. The piston must be able to bear both cyclic gas pressure and inertial forces while working. Pumps reverse the piston's function and transfer crankshaft comes to piston heads, they may be flat, convex or concave depending on the design of the combustion chamber. Despite the pressure in the cylinder, it is strong enough to handle it. In order to prevent gas from leaking out of the cylinders, piston rings are utilised.On the connecting rod's cylindrical walls, it serves as support for a side push. The hem of the dress. The skirtThe gudgeon pin or bracelet is another name for the piston pin. There is a risk of fatigue damage to the piston as a consequence of the piston connecting to the engine's connecting rod, such as piston lateral wear and piston head fractures.Aluminum is a popular material for pistons because of its low weight and ability to transmit heat. Because of its high expansion coefficient and poor

hot strength, it should not be used in high-temperature environments. An Overview of the Topics A pneumatic cylinder, for example, uses a piston as a mechanical component. Reciprocating pumps, engines, and gas compressors all use reciprocating motion. pistons, which are used with a piston, are responsible for vertical movement inside an enclosed cylinder. A column rod and/or a connecting rod in an engine are used to transmit the expanding gas's force to the cylindrical shaft via a connecting rod and/or column rod, respectively.





B. Piston Design Consideration Consider the following while designing a piston.The mass should be kept to a minimum.A low-noise, high-speed reciprocating system is necessary.High gas pressure and inertia forces need a high level of resistance. Lightweight is a must. 4) The product's construction must be sturdy to withstand heat and mechanical deformation.In order to prevent wear, a proper bearing surface area must be given. It is essential that the heat created by combustion be dispersed to the cylinder walls as quickly as feasible. 7) The piston pin should be adequately supported by this component. 8) It should be able to seal the cylinder with oil and gas.

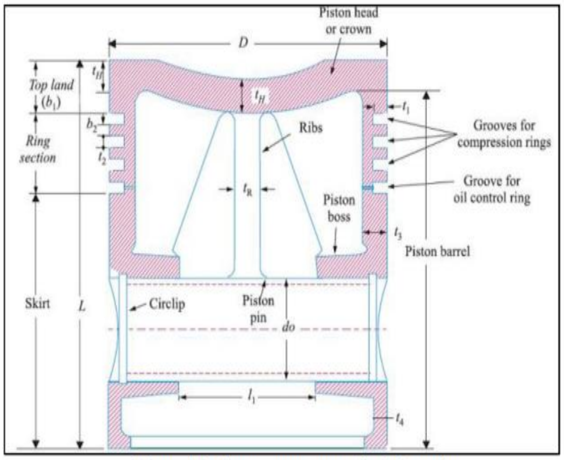


Figure 1. 3 Piston components for I.C. engine

The piston should be designed and analysed in line with thermal and structural considerations, as per the goals of the present study. The development of a combustion model and the use of CFD are both described. Thermodynamics of a gasoline engine. In reality, a four- or two-way thermodynamic assessment is not a straightforward process. Analysis may be much simpler if the information mentioned assumptions are adhered to. The Otto cycle is the resultant cycle that comes the closest to reflecting real operating circumstances. An electric current is created to ignite the gasoline when the engine is operating when the combustion of fuel is heated. At low rpms, around TDC, this happens (Top Dead Centre). It is possible for the gas charge to be ignited while it is still being compressed by raising engine rpm. Otto engines come in a wide variety of shapes and sizes, illustrating this advantage. Non-compression atmospheric engine efficiency was 14 percent. There was a 32 percent efficiency in the compressed charge engine. Analytically, the heat transfer from the piston ring to the cylinder is difficult because of a large number of conditions that occur throughout a four-time cycle. The following are a few examples of these situations: When the oil layer varies in thickness, it has a significant influence on heat conductivity, allowing piston rings and liners to come into direct touch with each other. When the rings are twisted during a stroke, the contact geometry may be altered. 4) The clearance between the piston ring and the line may be affected by variations in tolerances in piston ring production. Surface-to-surface or hydrodynamic friction may develop in the case of a ring liner contact, resulting in increased surface oil and temperature. The amount of piston ring contact may be altered by tilting the piston. Localized heat transmission to the piston top ground may be enhanced by the rising of combustion gases. 8) The geometry of the piston and piston ring is altered by thermal expansion of the piston and piston ring. Convective heat is added to the piston and cylinder lines when combustion gas blow-by occurs..

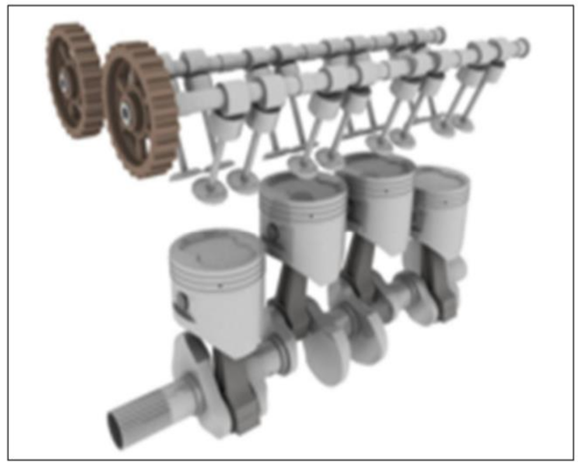


Figure 1. 4 Four Piston Engine moving parts

LITERATURE REVIEW

It's important to design and analyse the piston based on thermal and structural concerns for the purposes of this research. Combustion modelling and computational fluid dynamics (CFD) are both discussed. A gas engine's thermodynamics. An appraisal of thermodynamics in four or two ways is not as simple as it seems. If the previously specified assumptions about the data are followed, the analysis will be a lot easier. The resulting cycle, the Otto cycle, is the most accurate representation of actual operating conditions. When the engine is running and the combustion of fuel is heated, an electric current is generated to ignite the gasoline. During low-rpm operation (around TDC), this occurs (Top Dead Centre). By increasing engine rpm, it is possible to ignite the gas charge while it is still being compressed. This is shown by the fact that Otto engines exist in a broad range of designs and sizes. The atmospheric non-compression engine has a 14 percent efficiency. The compressed charge engine was 32% efficient. In a four-time cycle, there are several circumstances that complicate the mathematical analysis of the piston ring to cylinder heat transfer. A couple of these scenarios are as follows: This allows piston rings and liners to come into direct contact with each other when the oil layer is different in thickness. The contact geometry may be changed if the rings are twisted during a stroke. 4) Variations in tolerances in piston ring fabrication may alter the clearance between the piston ring and the line. In the event of a ring liner contact, increased surface oil and temperature might be the consequence of surface-to-surface or hydrodynamic friction. Tilting the piston may change the amount of piston ring contact. Combustion gases rising to the top of the piston may increase heat transfer to the ground below. Thermal expansion of the piston and the piston ring alters their geometrical properties. By-product combustion gas blow-by heats the piston and cylinder lines through convection.

PROBLEM STATEMENT

Sources and Processes 13 atomic, 26.98 atomic, and one stable isotope of aluminium (27.) are the chemical elements that make up aluminium. With a density of between 2,70 and 2,90 kg/dm3, aluminium has a melting point of 660°C and is soft and silver. Aluminium oxide forms a waterproof, thin layer when exposed to the air. Aluminum is an important construction material when used in combination with other metals. Aluminum is mostly found in the forms of oxide, hydroxide, chloride, sulphate, silicate, and acetate in these and a number of other chemical compounds in these and many more forms. It is a kind of cast iron with a graphitic microstructure that is utilised in the manufacturing of steel. In honour of the graphite-induced grey colour of the resulting fractures, it was given this moniker. As far as volumetric consumption goes, it's the most popular iron-casting alloy. Component stiffness is more important than component tensile strength in applications such as internal combustion engine cylinder blocks, pump housings, valve bodies and electrical boxes. Grey cast iron is often utilised in the manufacturing of cast iron cookware and disc brake rotors due to its high thermal conductivity and specific heat capacity.

Table 1. 1 Mechanical properties of the Material

Sl No	Properties	Aluminium	Grey Cast Iron
1	Density (Kg/m^3)	2880	7200
2	Young's Modulus (GPa)	115	124
3	Poisson's ratio	0.3	0.3
4	Bulk Modulus (MPa)	95.8	103.3
5	Shear Modulus (MPa)	44.23	47.69
6	Tensile Yield Strength (MPa)	480	240
7	Compressive Yield Strength (MPa)	480	600
8	Ultimate tensile strength (MPa)	650	276
9	Specific Heat (J/Kg C)	875	447

CATIAV5 is used to generate the motor piston model, and ANSYS is used to simulate the piston's performance. In a static structural analysis, pressure is applied to the piston's top to measure stress. Thermal analysis of the transient column is used to determine the column's temperature response. In thermal analysis, the temperature is used to measure changes in a substance's physical qualities. Mass and energy changes in a substance's sample are the most often used approaches. As a whole, this graph shows the aluminium piston heat flux statistic. Fig. 1 shows the temperature variation between the various piston heights in a stable condition and the restricted circumstances described in fig. The highest temperature possible.

STATIC ANALYSIS OF THE STRUCTURE

All movements, tensions, pressure and stresses that do not produce considerable inertia and damping may be detected using static structural analysis. Structural loads and reactions are considered to be stable, however this assumption is based on the assumption that structural loads and reactions will vary with time. Static structural loads may be handled using the ANSYS. In a static analysis, external forces and pressures may be employed as load types. Second, steady-state inertia (such as gravity or rotational velocity). There is an enforced 3Displacement (non-zero). 4) Thermostats (for thermal strain). Piston behaviour must be investigated to improve the efficiency of the engine. Alloy steel pistons are often used because of their strong thermal and structural resilience. We conduct a structural and thermal investigation to see whether the materials we selected for the piston are safe to use under the imposed load conditions. At the end, the results are compared. Continuous thermal piston analysis will benefit from the findings of this research. D. Finite Element Method Heat Transport Analysis A multidimensional heat transfer research may be carried out with the help of the Finite Element Method. Components that represent the object's body are used in this kind of solution. Each component embodies the structure's underlying physics, geometry, and materials. Shape functions define how the values of the nodes change as they go through the elements. Nodes in the element may vary, but three or four node elements are often utilised in a 2D analysis, whereas four or eight node elements are commonly used in 3D. Nodes have varying degrees of freedom depending on the kind of analysis they are being used for. In order to do finite element studies, a material or design computer model must be strained and analysed in order to get particular results. It is usually used to improve the present product or to create a completely new one. Use the present product or structure's current design as a basis for new service conditions. When a structure fails, FEA can help evaluate what design adjustments are necessary to address the new conditions. 2D modelling and 3D modelling are often utilised in the industrial industry. The results are less precise when 2D modelling is done on a conventional computer. It is possible to get better results using 3D modelling but it is inefficient on all but the fastest processors. Linear systems are less complex than non-linear systems because of this. The plastic deformation caused by nonlinear systems may go all the way to the point of material breakage.

PROBLEM SOLVING

a. Model in Geometric Space This piston model was built in CATIA V5 and loaded into ANSYS Workbench 18.1 for use in typical load analyses. After the study was completed, a comparison was made between standard steel piston structural steel, aluminium, and grey cast iron. After meshing the model, the boundary conditions are applied appropriately, and the final results are generated. The results of structural study of different materials, such as aluminium and cast iron, are shown in the accompanying graphic. tetrahedral parabola elements are used to create a finite element mesh (elements). Convergence is ensured by controlling the stress of vonisis. The mesh is generated automatically in the present study. The graphic shows an illustration of the piston mesh. The convection limit of the ANSYS model is impacted by the surface load on the outer surface. Due to direct contact with the gas, the top of the piston rises to an exceptionally high point. As a result, a temperature of 360 degrees is applied to the piston's upper surface. In the figure, the piston's thermal limit is shown

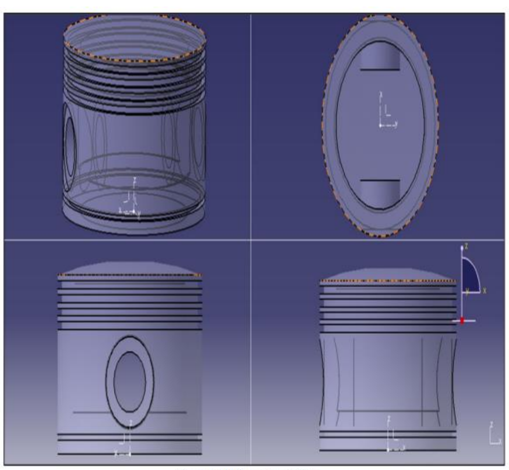


Figure 4. 1 Different view of Piston

Static Structural Analysis

During the combustion process, force is transmitted from the piston to the crankshaft. In addition, the piston is subjected to additional strain as a result of the igniting process. Frequent cycles or brief packing will not cause fatigue failure of the piston, which is exactly what it is designed to do: endure shock loads. A combination of shearing and bending stresses characterise classic internal combustion engines' gudgeon pins (which link the piston to the connecting rod). A piston's output and failure circumstances are largely determined by how much heat is deposited within it during combustion, and how much of that heat is then released as kinetic energy. Von Mises stress or tensile stress may be used to describe the yield requirements of Mises.

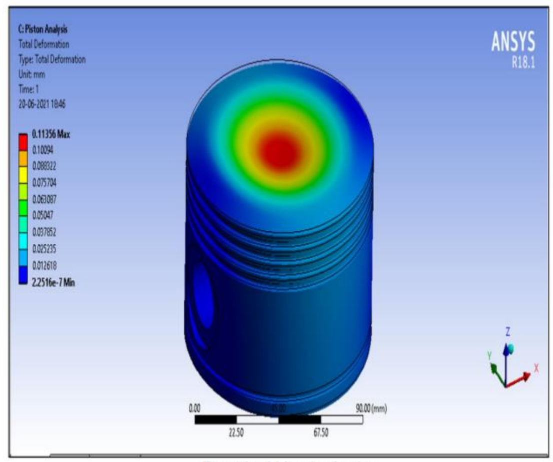


Figure 4. 2 total deformation of cast iron

Thermal Analysis

More than 80 percent of the IC pistons are made of aluminium alloy, as opposed to the cast iron used for the borer lining. This results in various operational and design explanations that are different. The alloy in the piston should never be heated to a temperature more than 60% of its melting point since doing so affects the crystalline structure of the alloy, making it less effective over the long run. Different piston surfaces were used to calculate heat transfer equations..

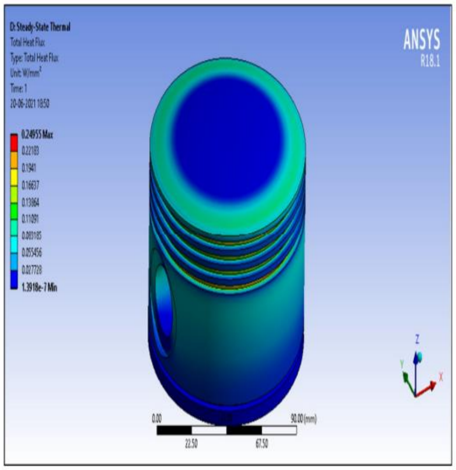


Figure 4. 3 heat flux

RESULT AND CONCLUSION

A piston made of a composite material (aluminium) has been created and tested. Aluminum pistons can withstand the rigours of ageing in even the most extreme environments. Compared to Grey cast iron, aluminium has less distortion, less stress and better temperature distribution. Some of the drawbacks of cast iron piston are alleviated by aluminium pistons. We learn a lot about aluminium and its properties via this investigation. It is because of the curvature of the piston crown that the most heat transfer happens across a smaller region. Although it's just a few millimetres thick, it's still quite hot. Despite the piston's lower level of stress, the observed deflection is rather large, as indicated in the figure. Pressure, deformation, fatigue life and piston temperature are shown in Figs 19–27. Stress, deflection, and temperature values are lower near the bottom of the piston, allowing for improvement. It was concluded that the piston's design parameter with modification was appropriate. Current results may be improved upon. There was a maximum stress of 264 MPa, which is less than the material's yield strength and maximum tensile stress (both of which are 650 MPa) (480 MPa). Thermal stress at 3600 has been calculated. Because our piston design has a minimum safety factor of 15, it can withstand the imposed load.

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