DESIGN AND ANALYSIS OF PISTON WITH COMPOSITE MATERIALS FOR AUTOMOTIVE APPLICATIONS

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Abstract: conversation system, piston plays a very important role. Piston endures the cyclic pressure and therefore the mechanical phenomenon forces at work and this operating condition could cause the fatigue injury of piston like piston head wear, piston head cracks. Piston failure takes place as a result of mechanical and thermal stresses. Compared to alternative components of IC engine, the piston works on terribly high thermal conditions and is that the foremost stressed part of the engine. the most objective is comparative study of pistons created from completely different materials by victimisation Finite part technique (FEM) and confirm the utmost mechanical and thermal stress ,fatigue strength functioning on the piston by making an attempt structural and transient thermal analysis. Here the period of the piston improves by suggests that of introducing a replacement composite matrix like atomic number 13 alloy with particulates of inorganic compound that has the utmost wear issue. The parameters used for the solid modeling and simulation ar operative pressure , temperature and material properties of piston. The specifications used for the study of those pistons belong to four stroke single cylinder engine of Bajaj neutron star 220 cc For solid modeling we tend to ar victimisation CATIA ,for meshing hyper mesh and ansys 18.0 use as a convergent thinker.

Materials propose: atomic number 13 alloy, Magnesium alloy and atomic number 22 alloy.

Investigations: mechanical and thermal stress, fatigue strength, Model analysis and weight

Bajaj neutron star four stroke 220 cc hydrocarbon engine. Input parameters for piston design

Bore (D) : 67 mm Stroke (L) : 62.4 mm Length of connecting rod: 124.8 mm
Displacement volume: 220 cm³ Compression ratio: 9.5+/-0.5:1 Maximum power: 15.51 kW at 8500 rpm
Maximum torque (T): 19.12 N-m at 7000 rpm(N)

Key words: piston, fatigue analysis, thermal analysis, material, hyper mesh

I. INTRODUCTION

A piston could be a part of mutual engines, mutual pumps, gas compressors, hydraulic cylinders and gas cylinders, among alternative similar mechanisms. it’s the moving part that’s contained by a cylinder and is formed airtight by piston rings. In associate engine, its purpose is to transfer force from increasing gas within the cylinder to the shaft via a connecting rod and/or rod. In a pump, the operate is reversed and force is transferred from the shaft to the piston for the aim of press or ejecting the fluid within the cylinder. In some engines, the piston additionally acts as a valve by covering and uncovering ports within the cylinder.

Problem Description:

In this paper the strain distribution is evaluated on the four stroke engine piston by victimisation FEA. The finite part analysis is performed by victimisation FEA computer code. The couple field analysis is done out to calculate stresses and deflection because of thermal hundreds and force per unit area. The materials utilized in this project ar atomic number 13 alloy and magnesium alloy and atomic number 22 alloy stuff. during this project the natural frequency and Vibration mode of the piston were additionally obtained and its vibration characteristics ar analyzed. With victimisation pc power-assisted style (CAD), UNIGRAPHICS computer code the structural model of a piston are going to be developed. what is more, the finite part analysis performed with victimisation computer code ANSYS.

Functions of the Piston:

1. To receive the thrust from the explosion and transmit the force to the shaft through’ rod.
2. To act as a seal in order that the high combustion pressure doesn't escape to the housing.
3. To function a guide and an impact for the rod tiny finish.

Components of Piston: The main parts of the piston ar as follows:


Types of Pistons: There ar 3 styles of pistons, every named for its shape:

Flat-top Pistons Dish Pistons Dome Pistons.

II. LITERATURE REVIEW

Ch. Venkata Rajan within the time of 2013 [1], they have contemplated a cylinder from an inexpensive model that has been thought-about within the blessing operate as a base model. some work has been done on the transcription streamlining with clear cylinders still as cylinders with limit covering as these days. Ajay Beam Singh et al. [2] printed the strain circulation and heat anxieties of three altogether distinctive nuclear variety 13 metal compound cylinders by abuse restricted part procedure within the
time of 2014. dictator Zhao [3] offered associate underlying investigation of the cylinder in 2012. He left the cylinder by confirmative of E programming bundle to assist and upgrade the look of the cylinder. Aditya Kumar Gupta et al. [4] examined the cylinder, that were includes of two stages. They were transcription and Examination. S.Srikanth Reddy et al. [5] in 2013 researched the nice and cozy examinations on a norm (uncoated) diesel cylinder. In 2012 Yaochen Xu et al. [6] skint down a cylinder by ANASYS programming to initiate the twisting, heat and stress dispersion of the cylinder. S. Bhattacharya et al. [7] broken away at a cylinder of a two-stroke flash begin burning motor that had most force of half-dozen.5 kW at five00 kindle. They were transcription and Examination. They utilised atomic number 13 4032 amalgam on the grounds that the cylinder material. Dr. L.N. Wan hade et al. [8] calculable the strain and temperature circulation on the foremost elevated surface of a cylinder, the first model of the cylinder would be created abuse CATIA V5 programming bundle. At that time they unknown the pc power-assisted style model into the Hyper Cross section for pure mathematics improvement and lattice reason. Amit B. Solankiet al. [9] delineated vogue investigation and streamlining of [*br1] breed Cylinder for four stroke single chamber 10 unit (7.35 kW) diesel. They utilised high strength made steel for cylinder crown and light-weight amalgam like atomic number 13 composite for cylinder divider. abuse FEM they examined the strain appropriation of cylinder and investigated the precise motor condition in the course of burning technique. to remain removed from the frustration of the cylinder, the burdens on account of ignition were pondered. SasiKiran Prabhalaa et al. [10] supplanted the cylinder steel leaves behind atomic number 13 components to cut back the heap. The strength of atomic number 13 components wasn’t decent contrasted with steel segments. Consequently, they were taking the atomic number 13 combination as a result of the atomic number 13 amalgam displays the strength greatly just like the steel.

III DESIGN CALCULATIONS OF DRIVE SHAFT

\[ IP = \text{indicated power produced inside the cylinder} \quad \eta = \text{mechanical efficiency} = 0.8 \quad L = \text{length of stroke, mm} \]

\[ n = \text{number of working stroke per minute} = \frac{N}{2} \quad N = \text{engine speed} \quad A = \text{cross-section area of cylinder, mm}^2 \]

\[ l_c = \text{Length of connecting rod, mm} \quad a = \text{acceleration of the reciprocating part, m/s}^2 \]

\[ m_p = \text{mass of the piston, Kg} \]

\[ V = \text{volume of the piston, mm}^3 \quad t_b = \text{thickness of piston head (mm)} \]

\[ D = \text{cylinder bore, mm} \]

\[ r = \text{crank radius, mm} \quad p_{\text{max}} = \text{maximum gas pressure/explosion pressure, MPA} \]

\[ \sigma_t = \text{allowable tensile strength} = 110\text{N/mm}^2 \]

\[ \sigma_s = \text{ultimate tensile strength, MPA} \]

\[ K = \text{thermal conductivity/mK} \]

\[ T_c = \text{temperature at the centre of the piston head, K} \]

\[ HCV = \text{Higher Calorific Value of fuel} = 47000 \text{KJ/kg} \]

\[ BP = \text{brake power of the engine per cylinder, KW} \]

\[ m = \text{mass of fuel used per brake power per second, Kg/kWs} \]

\[ C = \text{ratio of heat absorbed by the piston to the total heat developed in the cylinder is 0.05} \]

\[ P_e = \text{allowable radial pressure on cylinder wall} = 0.025\text{N/mm}^2 \]

\[ \alpha_t = \text{permmissible tensile strength for ring material} = 110\text{N/mm}^2 \]

\[ h = \text{axial thickness of piston ring, mm} \]

\[ h_t = \text{width of top land, mm} \]

\[ h_w = \text{width of ring land, mm} \]

\[ t_b = \text{thickness of piston barrel at the top end, mm} \]

\[ t_s = \text{thickness of piston barrel at open end, mm} \]

\[ l_t = \text{length of skirt, mm} \]

\[ \mu = \text{coefficient of friction} = 0.01 \]

\[ l = \text{length of piston pin in the connecting rod bush, mm} \]

\[ d_o = \text{outer dia of piston pin, mm} \]

Mechanical efficiency of the engine (\( \eta \)) = 0.8

\[ \eta = \frac{BP}{IP} \]

Therefore, \( ICP = \frac{BP}{\eta} = 14.015/0.8 = 17.518 \text{KW} \)

\[ \pi \times 1518 \times 1000 = P \times \frac{a}{4} \times 0.0624 \times 7000 = 1.137 \text{MPA} \]

Max pressure (\( p_w \)) = 10^6 \times 1.137 = 11.37 \text{MPA} \]

According to Grashaff's formula, thickness of piston is given by

\[ t_h = D \times \frac{\sqrt{2P_{\text{max}}}}{16\sigma_t} \quad \text{Where} \quad \sigma_t = 220\text{MPA} \quad D = 67\text{mm} \]

\[ P_{\text{max}} = 11.357 \text{MPA} \quad t_b = 6.595 \text{mm by using Empirical formula,} \]

\[ t_h = 0.032D + 1.5 \quad t_s = 3.644 \text{mm} \]

On the basis of Heat dissipation, the thickness of piston head is given by

\[ t_h = \frac{[C-HCV+m+BP]}{12.56K(t_c-t_e)+3600} \]

Where, C = ratio of heat absorbed by piston to the total heat developed in the cylinder = 0.05

HCV = Higher calorific Value of fuel = 47000 KJ/kg, m = mas of fuel used per brake power per second = 28\times10^{-3} \text{Kg/kWs} K = \text{Thermal Conductivity (W/mK)} = 180 \text{W/MK} \]

At 75°C or 333.15 K for AL based alloys

Substitute the parameters in above equation,

\[ t_h = 3.45 \text{mm} \]

Comparing the above values for maximum piston head thickness is 6.59 mm

So, \( t_s = 6.595 \text{mm} \)

Piston Rings: The radial width of the ring is given by

\[ b = D \times \sqrt{\frac{2P_w}{\sigma_p}} \quad \text{Where,} \quad P_w = 0.025 \text{N/mm}^2 \quad \sigma_p = 110 \text{MPA} \]

Substitute the parameters in above equation,

\[ b = 1.7494 \text{mm} \]

Axial Thickness of Piston rings:

\[ h = 0.7b + b = 1.2243 \text{mm} \]

Width of the top land:

\[ h_t = t_h + 1.2t_h = 7.8 \text{mm} \]

Width of the ring land:

\[ h_2 = 0.75hto h = 0.9182 \text{mm} \]

Piston Barrel:

Thickness of piston barrel at the top end:

\[ t_1 = 0.03D + b = 4.9 = 8.6594 \text{mm} \]

Length of skirt:

\[ l_s = 0.6D + 0.8D = 40.2 \text{mm} \]

Length of piston pin at connecting rod bush:

\[ L_t = 0.45 \text{of Pistondia} = 30.15 \text{mm} \]

Piston pin diameter:

\[ d_o = 0.2BD + 0.3BD = 18.76 \text{mm} \]

Centre of piston pin should be 0.02D to 0.04d above the centre of skirt.
IV. COMPOSITE MATERIALS

Composite encompass 2 or a lot of material part that ar mix to supply a cloth that has superior properties to those of its individual constituent. Innovatively the most composite at those wherever the scattered stage is as fiber. The composite materials will be sorted supported miniature styles, multi stages, fortifications, means of pressing of filaments superimposed structures, technique for organizations, grid framework, handling methods, so forth Composite materials will be classified as:


**Aluminium alloy:** Aluminium alloys (or atomic number 13 alloys; see orthography differences) ar alloys within which atomic number 13 (Al) is that the predominant metal. The everyday alloying parts ar copper, magnesium, manganese, silicon, tin and metallic element. There ar 2 head characterizations, specifically jutting compounds and designed amalgams, the 2 of that ar to boot partitioned off into the classifications heat-treatable and non-heat-treatable.

**Material Properties of Metal Alloy**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Density</td>
<td>2770 Kg m⁻³</td>
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<tr>
<td>Young’s Modulus</td>
<td>71000 MPa</td>
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<tr>
<td>Poisson’s Ratio</td>
<td>0.33</td>
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<tr>
<td>Tensile Modulus</td>
<td>114285.71 MPa</td>
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<tr>
<td>Compressive Modulus</td>
<td>280 MPa</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>26692 MPa</td>
</tr>
<tr>
<td>Tensile Ultimate Strength</td>
<td>310 MPa</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>175 @ 21TWm⁻¹ C⁻¹</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>2.3E⁻⁰⁵ C⁻¹</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>875 J Kg⁻¹ C⁻¹</td>
</tr>
</tbody>
</table>

**Titanium alloy:** Titanium alloys square measure mixtures of atomic number 12 with different metals (called associate alloy), usually Al, zinc, manganese, silicon, copper, rare earths and atomic number 40. Atomic number 12 is that the lightest structural metal. Atomic number 12 combos have a hexagonal grid structure, that influences the crucial properties of those compounds.

**Material properties of Magnesium Alloy**

<table>
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<tr>
<td>Density</td>
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<tr>
<td>Young’s Modulus</td>
<td>45000 MPa</td>
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<tr>
<td>Poisson’s Ratio</td>
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<tr>
<td>Tensile Modulus</td>
<td>193 MPa</td>
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<tr>
<td>Compressive Modulus</td>
<td>193 MPa</td>
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<tr>
<td>Tensile Ultimate Strength</td>
<td>255 MPa</td>
</tr>
<tr>
<td>Bulk Modulus</td>
<td>50000 MPa</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>16667 MPa</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>156 @ 21TWm⁻¹ C⁻¹</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>2.6E⁻⁰⁵ C⁻¹</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>1024 J Kg⁻¹ C⁻¹</td>
</tr>
</tbody>
</table>

**MATERIALS**

**Ceramic Materials**

- **Thermal conductivity:** 2.6E⁻⁰⁵ C⁻¹
- **Specific heat:** 875 J Kg⁻¹ C⁻¹

**Graphite**

- **Specific heat:** 930 J Kg⁻¹ C⁻¹

**Metallic Materials**

- **Thermal conductivity:** 175 @ 21TWm⁻¹ C⁻¹
- **Specific heat:** 875 J Kg⁻¹ C⁻¹

**Superconducting Materials**

- **Specific heat:** 0.33 J Kg⁻¹ C⁻¹

**Composites**

**Design software (CATIA):** CATIA-Computer motor-assisted 3 Dimensional Interactive Application could be a 3D Product Lifecycle Management software package suite developed by French Company Dassault Systems. CATIA Facilitates cooperative engineering across disciplines with its 3D expertise platform. CATIA permits the user to make elements in high productive and intuitive atmosphere. CATIA enriches exciting product style with basic half and surface style tools; simply established assembly constraints, mechanically positions elements and check assembly consistency.

**DESIGN OF THE PISTON**

**Fig 5.1:** CATIA User Interface

**Fig 5.2:** Command being selected from Menu bar

**Fig 5.3:** Plane being selected

**Fig 5.4:** Work bench being selected

**Fig 5.5:** Toolbar Listed

**Fig 5.6:** Profile of the Piston
Fig 5.7: Shaft operation to profile of Piston  
Fig 5.8: Pin Profile of the Piston  
Fig 5.9: Pin profile of the Piston  

Fig 5.10: lower phase of the Piston  
Fig 5.11: Pocket of lower profile of the Piston  
Fig 5.12: Profile on the Pin of the Piston  

Fig 5.13: Pocket operation on the Pin  
Fig 5.14: Mirror operation of Pocket Pin  
Fig 5.15: Profile for the Groove at the Pin  

Fig 5.16: Groove operation at the Pin  
Fig 5.17: Mirror operation of Groove at Pin  
Fig 5.18: Design of the Piston  

Meshing software (HYPERMESH):
Altair Hyper Mesh™ could be a market-leading, multi-disciplinary finite component pre-processor, that manages the generation of the biggest, most complicated models, beginning with the import of a CAD pure mathematics to commercialism ready-to-run thinker file. Over the last twenty years, Hyper Mesh has evolved into the leading premier pre-processor for idea and sound reproduction modeling. The advanced pure mathematics associated meshing capabilities give an atmosphere for speedy model generation. The capability to make high notch network apace is one in all Hyper Cross section's center skills.

shut the Loop Between CAD and FEA: Extract shell meshes straight from a thin pure mathematics further as thickness assignments with the powerful Mid-map Mesh Generation tools. Extract composite data from maths files and transfer it to finite half data with lowest user interaction. Retrieve 3D CAD geometries from finite half models to talk vogue direction to vogue and engineering teams.

CAPABILITIES:
Best in school Meshing Mesh Morphing Batch Meshing High Fidelity Meshing
High Fidelity Meshing: Surface meshing Solid map hex meshing characin fish meshing
CFD meshing SPH meshing

CAD Interoperability: active Mesh provides import and export support for industry-leading CAD information formats. Moreover, Hyper Mesh has sturdy tools to clean up foreign pure mathematics to permit for the economical generation of high-quality meshes. Boundary conditions may also be applied on to pure mathematics for automatic mapping to underlying parts.

CATIA and CATIA CompositeLink  FiberSim  IGES (import and export)  Intergraph
JT (import and export)  Para solid (import and export)  ProE and CREO
SolidWorks  STEP (import and export)  Tribon  UG

Connectors: Connectors square measure geometric entities accustomed connect pure mathematics or iron entities. they are accustomed produce spot- and seam welds, adhesives, bolts or lots. Connectors square measure usually accomplished from

VL MESHING OF THE PISTON
geometric entities into numerous thinker specific iron representations. it's potential to unfulfilled them to vary the illustration to a special sort or thinker profile on resulting realization.

Composites: HyperMesh holds robust options for modeling extremely troublesome composites structures. Ply entities permit shaping the form of each single layers supported pure mathematics or parts. The laminate entity defines the stacking order of a composite half. The composites definition is generic and may be accomplished into several thinker profiles.

CAE {solver|problem thinker|convergent thinker|thinker} Interfacing: HyperMesh supports variety of assorted solver formats for each import and export. together with absolutely supported solvers, Hyper Mesh provides a very tailored atmosphere (user profile) for each supported thinker. It conjointly provides the pliability to support further solvers through a singular and straightforward interfacing language

Meshing method

Fig 6.1: Hyper mesh Workspace
Fig 6.2: Importing model
Fig 6.3: Mesh of the Piston

VII. ANALYSIS OF THE PISTON

Analysis software(ANSYS): ANSYS could be a software package package that enables you to digitally model planet phenomena. It uses computer-based numerical techniques to resolve physics issues. The vary of issues ANSYS will solve is vast and will be something from fluid flow, heat transfer, stress analysis and additional. The real power of associate FEA or CFD package like ANSYS is that it will solve issues that don't seem to be amenable to associate analytical approach. That is, they are doing not have commonplace formulae. Now, with the arrival of low-cost utility computing within the type of cloud, you'll be able to extremely push the boundaries of what are often shapely on the pc.

Analysis process:

Fig 7.1: Fixed Support
Fig 7.2: Friction-less Support
Fig 7.3: Pressure Load
Fig 7.4: Temperature Load
Fig 7.5: Convectional Support

VIII. FINITE ELEMENT ANALYSIS

Introduction: Finite component Analysis (FEA) could be a computer-based numerical technique for calculative the strength and behavior of engineering structures. It are wont to calculate deflection, stress, vibration, buckling behaviour and lots of different phenomena. It can also be wont to analyze either little or largescale deflection beneath loading or applied displacement. It uses a numerical technique referred to as the finite component technique (FEM). In finite component technique, the particular time is delineated by the finite parts. These parts square measure thought-about to be joined at such joints referred to as nodes or nodal points. In this project finite component analysis was applied mistreatment the FEA software package ANSYS. the first unknowns during this structural analysis square measure displacements and different quantities, like strains, stresses, and reaction forces, square measure then derived from the nodal displacements.

Static analysis: Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis are often either linear or non-linear. every kind of non-linearities square measure allowed like giant deformations, plasticity, creep, stress stiffening, contact parts etc. this chapter focuses on static analysis.

Transient Thermal Analysis: A transient thermal analysis calculates temperatures and fluxes in your model over a specific time vary. If you're not inquisitive about the variation of temperature over time, you must use steady thermal analysis instead. you'll be able to direct style Simulate to report full results or temperature hundreds at such time intervals.
Analysis Results:

IX. RESULTS

Static Structural Analysis Results:

Total Deformation of the Piston:

Aluminium Alloy

Magnesium Alloy

Titanium Alloy

Fig 9.1.1: Total Deformation

Fig 9.1.2: Total Deformation

Fig 9.1.3: Total Deformation

Directional Deformation of the Piston:

Aluminium Alloy

Magnesium Alloy

Titanium Alloy

Fig 9.1.4: Directional Deformation

Fig 9.1.5: Directional Deformation

Fig 9.1.6: Directional Deformation

Max. Principal Stress of the Piston:

Aluminium Alloy

Magnesium Alloy

Titanium Alloy

Fig 9.1.7: Max. Principal Stress

Fig 9.1.8: Max. Principal Stress

Fig 9.1.9: Max. Principal Stress

Shear Stress of the Piston:

Aluminium Alloy

Magnesium Alloy

Titanium Alloy

Fig 9.1.10: Shear Stress

Fig 9.1.11: Shear Stress

Fig 9.1.12: Shear Stress

Shear Elastic Strain of the Piston:

Aluminium Alloy

Magnesium Alloy

Titanium Alloy

Fig 9.1.13: Shear Elastic Strain

Fig 9.1.14: Shear Elastic Strain

Fig 9.1.15: Shear Elastic Strain
Equivalent Stress of the Piston:
- Aluminium Alloy
- Magnesium Alloy
- Titanium Alloy

![Fig 9.1.16: Equivalent Stress](image1)

Equivalent Elastic Strain of the Piston:
- Aluminium Alloy
- Magnesium Alloy
- Titanium Alloy

![Fig 9.1.19: Equivalent Elastic Strain](image2)

Max. Shear Stress of the Piston:
- Aluminium Alloy
- Magnesium Alloy
- Titanium Alloy

![Fig 9.1.22: Max. Shear Stress](image3)

Max. Shear Elastic Strain of the Piston:
- Aluminium Alloy
- Magnesium Alloy
- Titanium Alloy

![Fig 9.1.25: Max. Shear Elastic Strain](image4)

Normal Stress of the Piston:
- Aluminium Alloy
- Magnesium Alloy
- Titanium Alloy

![Fig 9.1.28: Normal Stress](image5)
Normal Elastic Strain of the Piston:
Aluminium Alloy  
Magnesium Alloy  
Titanium Alloy

Strain Energy of the Piston:
Aluminium Alloy  
Magnesium Alloy  
Titanium Alloy

Safety Factor of the Piston:
Aluminium Alloy  
Magnesium Alloy  
Titanium Alloy

Temperature of the Piston:
Aluminium Alloy  
Magnesium Alloy  
Titanium Alloy

Total Heat Flux of the Piston:
Aluminium Alloy  
Magnesium Alloy  
Titanium Alloy

Fig 9.1.31: Normal Elastic Strain  
Fig 9.1.32: Normal Elastic Strain  
Fig 9.1.33: Normal Elastic Strain  
Fig 9.1.34: Strain Energy  
Fig 9.1.35: Strain Energy  
Fig 9.1.36: Strain Energy  
Fig 9.1.37: Safety Factor  
Fig 9.1.38: Safety Factor  
Fig 9.1.39: Safety Factor  
Fig 9.2.1: Temperature of the Piston  
Fig 9.2.2: Temperature of the Piston  
Fig 9.2.3: Temperature of the Piston  
Fig 9.2.4: Total Heat Flux  
Fig 9.2.5: Total Heat Flux  
Fig 9.2.6: Total Heat Flux
### Tabular Results

#### Static Structural Tabular Results

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#### Directional deformation:

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### Material Properties

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### Shear Elastic Strain

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<td>3.81E-05</td>
</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>7.17E-05</td>
</tr>
</tbody>
</table>

### Normal Stress

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Normal stress, Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>Al</td>
<td>-205.81</td>
</tr>
<tr>
<td>2</td>
<td>Magnesium</td>
<td>-210.99</td>
</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>-213.71</td>
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</table>

### Normal Elastic Strain

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Normal elastic strain, mm/mm</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
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<td>Al</td>
<td>-1.98E-03</td>
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<tr>
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<td>Magnesium</td>
<td>-3.15E-03</td>
</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>-1.48E-03</td>
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</tbody>
</table>

---

Table 9.1.1: Total Deformation of the materials

Table 9.1.2: Directional Deformation of the materials

Table 9.1.3: Max. Principal Stress of the materials

Table 9.1.4: Shear Stress of the materials

Table 9.1.5: Shear Elastic Strain of the materials

Table 9.1.6: Equivalent Stress of the materials

Table 9.1.7: Equivalent Elastic Strain of the materials

Table 9.1.8: Max. Shear Elastic Strain of the materials

Table 9.1.9: Max. Shear Stress of the materials

Table 9.1.10: Normal Stress of the materials

Table 9.1.11: Normal Elastic Strain of the materials
Table 9.2.1: Temperature of the materials

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Temperature, °C</th>
</tr>
</thead>
<tbody>
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<td>Ti</td>
<td>22.00</td>
</tr>
<tr>
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<td>Al</td>
<td>22.01</td>
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<tr>
<td>3</td>
<td>Mg</td>
<td>21.39</td>
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</table>

Table 9.2.1: Total Heat Flux of the materials

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Total Heat Flux, W/mm²</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Al</td>
<td>1.28E-11</td>
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<tr>
<td>2</td>
<td>Mg</td>
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<tr>
<td>3</td>
<td>Ti</td>
<td>9.33E-11</td>
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</table>

Graph 9.1.1: Total Deformation of the materials

Graph 9.1.2: Directional Deformation of the materials

Graph 9.1.3: Max. Principal Stress of the materials

Graph 9.1.4: Shear Stress of the materials

Graph 9.1.5: Shear Elastic Strain of the materials

Graph 9.1.6: Equivalent Elastic Strain of the materials

Graph 9.1.7: Max. Shear Elastic Strain of the materials

Graph 9.1.8: Max. Shear Stress of the materials
The deformation of titanium alloy is 0.07179mm lower than the other two materials. Also, the FOS of Titanium alloy is 1.7 is higher than the other materials, so further development of high power engine using this material is possible.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Total deformation, mm</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>Magnesium</td>
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</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>0.07179</td>
</tr>
</tbody>
</table>

REFERENCES

[6] Yaochen Xu, Mo Yang. “Structure style and Simulation of metallic element Engine Piston supported Thermal-Mechanical Coupling Model” This work was applied at the Department of applied science, Bleking Institute of Technology, Karlskron, Sverige underneath the management of Dr. Mats Walte and student student Massimo Panarotto. Oct 2012.