Design and Comparative Analysis of Piston by ANSYS

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Abstract

Piston plays a main role in energy conversation. Failure occurred of piston due to various thermal and mechanical stresses. The working condition of the piston is so worst in comparison of other parts of the internal combustion engine. The main objective of this work is to investigate and analyze the stress distribution of piston. Design and analysis of an IC engine piston using three different materials that are used in this project. Taking pulsar 220 cc piston for making 3D model. Analysis is carried out on aluminum alloy have been selected for structural and thermal analysis of piston. In this project find that the value of displacement, Stress and Factor of safety of all 3 material. This result is compare. Finally find out which one is the suitable material on piston in these three materials. Design of the piston is carried out using CATIA v5, static analysis is performed using ANSYS 12 by Finite Element Analysis (FEA).

Keywords: ANSYS, FEA, CAD, CATIA

I. INTRODUCTION

The modern trend is to develop IC Engine of increased power capacity. One of the design criteria is the endeavor to reduce the structures weight and thus to reduce fuel consumption. This has been made possible by improved engine design. These improvements include increased use of lightweight materials, such as advanced ultra-high tensile strength steels, aluminum and magnesium alloys, polymers, and carbon-fiber reinforced composite materials. The integration of lighter weight materials is especially important if more complex parts can be manufactured as a single unit. In the next 10–20 years, an additional 20–40% reduction in overall weight, without sacrificing safety, seems to be possible. Cuddy et al (1997) have reported that for every 10% weight reduction of the vehicle, an improvement in fuel consumption of 6–8% is expected. Improved engine design requires optimized engine components. Therefore sophisticated tools are needed to analyze engine components. Engine piston is one of the most analyzed components among all automotive or other industry field components. The engine can be called the heart of an automobile and the piston may be considered the most important part of an engine. Many sophisticated Aluminum piston analysis methods have been reported in the past years. Silva 2006 has analyzed fatigue damaged piston. Damages initiated at the crown, ring grooves, pin holes and skirt are assessed. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work. A linear static stress analysis, using ‘‘cosmos works’’, is used to determine the stress distribution during the combustion. Stresses at the piston crown and pin holes, as well as stresses at the grooves and skirt as a function of land clearances are also present. All we do is buy our vehicles, hop in and drive around. There is, however, a history of development to know about. The compact, well-tuned, powerful and surprisingly quiet engine that seems to be purr under your vehicle’s hood just wasn’t the tame beast it seems to be now. It was loud, it used to roar and it used to be rather bulky. In fact, one of the very first engines that had been conceived wasn’t even like the engine we know so well of today. An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel. The internal combustion engine was conceived and developed in the late 1800s Internal combustion engines can deliver power in the range from 0.01 kW to 20x103 kW, depending on their displacement. The complete in the market place with electric motors, gas turbines and steam engines. The major applications are in the vehicle (automobile and truck), railroad, marine, aircraft, home use and stationary areas. The vast majority of internal combustion engines are produced for vehicular applications, requiring a power output on the order of 102 kW. Next to that internal combustion engines have become the dominant prime mover technology in several areas. For example, in 1900 most automobiles were steam or electrically powered, but by 1900 most automobiles were powered by gasoline engines. As of year 2000, in the United States alone their internal combustion engines. In 1900, steam engines were used to power ships and railroad locomotives; today two- and four-stoke diesel engines are used. Prior to 1950, aircraft relied almost exclusively on the pistons engines. Today gas turbines are the power plant used in large planes, and piston engines continue to dominate the market in small planes. The adoption and continued use of the internal combustion engine in different application areas has resulted from its relatively low cost, favorable power to weight ratio, high efficiency, and relatively simple and robust operating characteristics of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall.

Fig 1 : Piston

II. COMPUTER AIDED MANUFACTURING PROCEDURE

Computer-aided design (CAD) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. Each stage requires specific knowledge and skills and often requires the use of specific software.

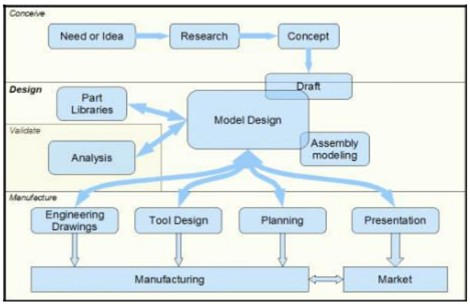

Fig 2: Computer Aided Manufacturing Procedure

A. Need Or Idia

Usually, the design process starts with a defined need. The need can be defined by market research, by the requirements of a larger body of work (for example airplane part). Sometimes, but more rarely than you may think, the design process is begun with a new idea or invention. At any rate, a needs analysis should precede any decision to undertake a project. This includes defining the need in a highly detailed way, in writing. This is similar to the requirements specification process in software engineering.

B. Research

Professionals tend to research available solutions before beginning their work. There is no need to "reinvent the wheel". You should study existing solutions and concepts, evaluating their weaknesses and strengths. Your research should also cover available parts that you can use as a part of your design. It is obvious, that Internet and search engines like Google are very helpful for this task. There are also many libraries of standardized parts which you can import into your project.

C. Concept

Based on your research, start with a high level concept. You should specify the main principles and major parts. For example, you can consider Diesel or Sterling engines for stationary electric generators.

D. Draft

You can choose to create a draft by pen and paper. Some prefer to use simple vector graphics programs, others even simple CAD (for example Smart Sketch), yet others prefer to start directly in their main CAD system.

E. Model Design

2D and 3D modeling in CAD. The designer creates a model with details, and this is the key part of the design process, and often the most time consuming. This will be described in greater detail in further lessons.

F. Part Libraries

Standard parts, or parts created by other team members, can be used in your model (you don't have to reinvent the wheel). Files representing a part can be downloaded from the Internet or local networks. They are also distributed on CD ROMs or together with CAD as an extension (library). By putting these predefined parts into your project, you ensure that they are correct and save a lot of time and effort. When working on a large project, this becomes a requirement to ensure the parts operate together, swap out equivalent parts, and coordinate distributed teams' work. This was, a standard part can be inserted into the project by one team member.

G. Assembly modeling

Parts are assembled into a machine or mechanism. Parts are put together using mating conditions such as alignment of the axis of two holes. More about how to do this in further lessons. Cad is used in industries. Assembly modeling is a technology and method used by computer-aided design and product visualization computer software systems to handle multiple files that represent components within a product. The components within an assembly are represented as solid or surface models. The designer generally has access to models that others are working on concurrently. For example, several people may be designing one machine that has many parts. New parts are added to an assembly model as they are created. Each designer has access to the assembly model, while a work in progress, and while working in their own parts. The design evolution is visible to everyone involved. Depending on the system, it might be necessary for the users to acquire the latest versions saved of each individual component to update the assembly.

The individual data files describing the 3D geometry of individual components are assembled together

III.

through a number of sub-assembly levels to create an assembly describing the whole product. All CAD and CPD systems support this form of bottom-up construction. Some systems, via associative copying of geometry between components also allow top-down method of design.

Components can be positioned within the product assembly using absolute coordinate placement methods or by means of mating conditions. Mating conditions are definitions of the relative position of components between each other; for example alignment of axis of two holes or distance of two faces from one another. The final position of all components based on these relationships is calculated using a geometry constraint engine built into the CAD or visualization package.

H. Engineering Drawings

From your 3D models, you generate a set of engineering drawings for manufacturing. These drawings are then distributed to the departments and individuals responsible for producing that work. Also, these drawings must be tolerance for proper manufacturing. An engineering drawing, a type of technical drawing, is used to fully and clearly define requirements for engineered items.

Engineering drawing (the activity) produces engineering drawings (the documents). More than merely the drawing of pictures, it is also a language a graphical language that communicates ideas and information from one mind to another.

Engineering drawing and artistic types of drawing, and either may be called simply "drawing" when the context is implicit. Engineering drawing shares some traits with artistic drawing in that both create pictures. But whereas the purpose of artistic drawing is to convey emotion or artistic sensitivity in some way (subjective impressions), the purpose of engineering drawing is to convey information (objective facts). One of the corollaries that follow from this fact is that, whereas anyone can appreciate artistic drawing (even if each viewer has his own unique appreciation), engineering drawing requires some training to understand (like any language); but there is also a high degree of objective commonality in the interpretation (also like other languages). In fact, engineering drawing has evolved into a language that is more precise and unambiguous than natural languages; in this sense it is closer to a programming language in its communication ability. Engineering drawing uses an extensive set of conventions to convey information very precisely, with very little ambiguity.

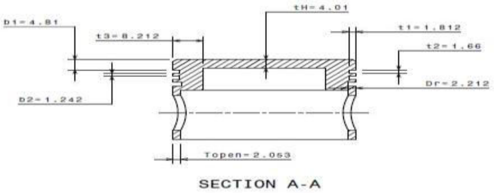

Fig 3: Cross sectional side view of Piston

I. About CATIA V5

CATIA (an acronym of computer aided three-dimensional interactive application) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systems. CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted by the aerospace, automotive, shipbuilding, and other industries

FEA is a numerical method. It is very commonly used in finding the solution of many problems in engineering. The problem includesdeigning of the shaft, truss bridge, buildings heating and ventilation, fluid flow, electric and magnetic field and so on. The main advantage of using finite element analysis is that many designs can be tried out for their validity, safety and integrity using the computer, even before the first prototype is built. Finite element analysis uses the idea of dividing the large body in to small parts called elements, connected at predefine points called as nodes. Element behavior is approximated in terms of the nodal variables called degrees of freedom. Elements are assembled with due consideration of loading and boundary condition. This results in a finite number of equations. A solution of these equations represents the approximate behavior of the problem. The design and analysis have done with the 3D modeling software and FEA technique standard FEM tool. The analysis is carried out by using the ANSYS software. This gives the comparison between analytic and numerical value. Part is drawn in CAD software. The CAD software which is involved in this is CATIA and this part is a call to ANSYS in (.igs) format.

III. FINITE ELEMENT METHOD (FEM)

FEA is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally requires the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method approximates the unknown function over the domain. To solve the problem, it subdivides a large system into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

VI. PROCEDURE FOR FEA

There are a number of steps in the solution procedure using finite element method. All finite element packages require going through these step.

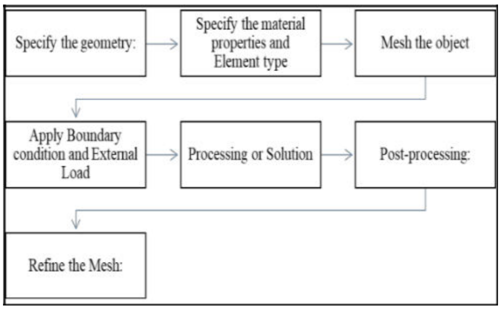

Fig 4: Design procedure

1. Specify the geometry: - In this import the geometry from CAD software to FEA software.
2. Specify the material properties and Element type: - In this step, the selection of element type is done and the material properties are given. The Young's modulus and Poisson's ratio are the input for material properties.
3. Mesh the object: - Here the object is broken in to small elements. This involves defining the type of element into which structure will be broken as well as specifying how the structure will be divided in to the element. This subdivision in to elements can either be input by the user or with same finite element programs can be chosen automatically.
4. Apply Boundary condition and External Load: - This is followed by specifying the boundary condition and the external loads are specified.
5. Processing or Solution: - The modified algebraic equations are solved to find the nodal values of the primary variable.
6. Post-processing: - It involves improving the result of processing in to the model. These results are graphically displaced to enable user case of high deflection and stress.
7. Refine the Mesh: - For the case of a judge of the accuracy of the result, there is need to increase or decrease no of elements of an object.

V. THEORETICAL CALCULATION FOR PISTON

1) Torque

P= 2πNT/60

We know that p=5.6 kW

$5.6\times e^{3} = 2\times3.14\times7500\times T / 60$

T=7.130 N-m

2) Diameter of piston

Π^{2} h = cc

Cylinder area = displacement

We know that displacement so to find diameter of piston

$3.14\times r^{2} \times 0.049 = 97\times E^{-5}\ m^{3}$

r = radius

Diameter D = 2×r

D = 2×0.025 m =0.05m=50mm

3) Cylinder inside pressure

Pressure = force/area (F/A)

Force =power/velocity (P/V)

We know that power

Velocity =2LN/60=2× 0.049×5000/60=

8.16M/S Force =5.6e3 /8.16 = 686.274N P=F/A

Area = πr 2 = $3.14\times (0.025)^{2} = 1.934E^{-3}\ M^{2}$

$P = 686.27/1.934E^{-3} = 0.34953$Mpa

(minimum) Maximum pressure =15 Pmin

P max =15× 0.34953 =5.24 Mpa

Max pressure = 5.24 Mpa

VI. DESIGN SPECIFICATION

1) Thickness of piston head

$$t_H = D\sqrt{\frac{3}{16} * \frac{P}{\sigma_t}}\ (\text{in mm})$$

Where

P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston in mm.

σt = permissible tensile stress for the material of the piston.

tH = 4.01mm

2) Radial thickness of ring (t1)

$$t_1 = D\sqrt{\frac{3 * P_w}{\sigma_t}}\ (\text{in mm})$$

Where,

D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from

0.042N/mm². to 0.0667 N/mm² For present material, σt is 152.2Mpa

t_1 =1.812mm

3) Axial thickness of ring (t_2)

The thickness of the rings may be taken as

$t_2 = 0.7t_1$ to t_1

t_2 = 0.92×1.812

t_2 =1.66mm

4) Top land thickness (b_1)

The width of the top land varies from

b1= t_H to 1.2 t_H

b1=1.2 x 4.01

b =4.81mm

5) Thickness of other land (b_2)

b_2= 0.75 t2 to t2

b_2= 0.75 ×1.66

b = 1.242mm

6) Maximum thickness of barrel (t_3)

t_3 =0 .03D+b+4.5mm

b = t_1+0.4

b = 1.812+0.4

b = 2.212mm

t_3= 0.03 D + 2.212+ 4.5mm

= 8.212mm

7) open end of the barrel thickness (T open)

At the open end the thickness is taken as

T open = (0.20 to0.30Tp)

T open = 0.25 x 8.212 =2.053

T open = 2.053mm

8) Gap between the rings (T L)

T L= 0.055 × D

T L =2.75 mm

Second ring = 0.04 D =0.04 ×50 = 2.00mm

9) Depth of ring groove (Dr)

Dr = t_1 + 0.4

Dr = 1.812 +0.4

Dr = 2.212 mm

10) Length of piston

$L_p = L_{ps} + 3\times t_1 + 3 \times Dr$

Here Lps is taken nearly as 0.5 of the piston diameter

(0.5D)

LPs =0.5D =0.5 ×50 = 25

LPs = 25

LP = 25 + 3× 1.812 + 3 ×2.212

LP = 37.072mm

11) Piston pin diameter

Pdo = 0.3D to 0.45D,

Pdo = 0.32× 50

Pdo = 16mm

Pdi=0.75× Pdo=0.75×16

Pdi = 12mm

VII . STATIC ANALYSIS

The objective of this analysis is to obtain a practical validation for the theoretical results. The computer compatible mathematical description of the geometry of the object is called geometric modeling. CATIA is basically CAD (computer-aided design) software that allows the mathematical description of the object to be displayed and manipulated as the image on the monitor of the computer [7], whereas, ANSYS is a engineering simulation software that predicts with confidence about the performance of the product under the real-world environments incorporating all the existing physical phenomena. The layout of static analysis involves meshing, boundary conditions and loading.

A. Meshing of Piston

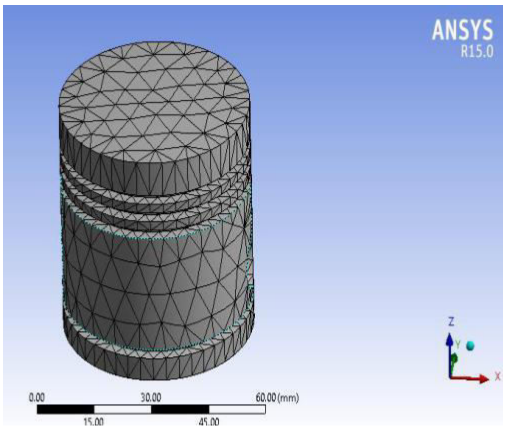

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Fig.5: Meshing of piston

Node	8498
Element	4136

Table 1.Meshing

B. For Aluminum Alloy:
Boundary Condition

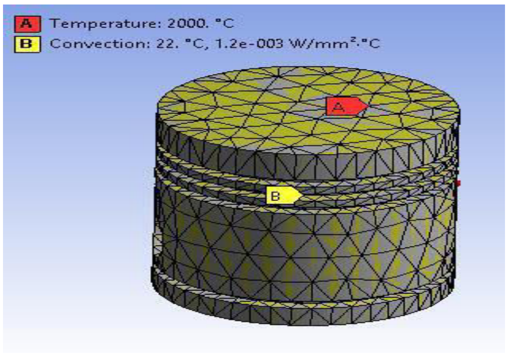

Fig 6: Boundary Condition

C. *For Aluminum Alloy Temperature*

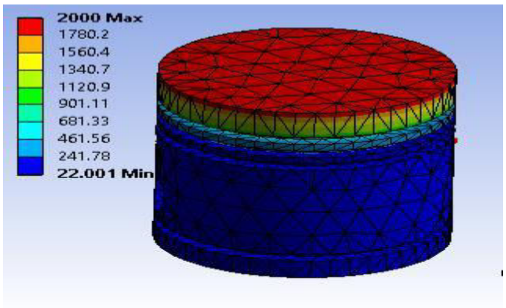

Fig 7: For Aluminum Alloy Temperature

Results	
Minimum	22.001 °C
Maximum	2000. °C

Table 2.Temperature of global minimum for aluminum alloy

Time [s]	Minimum [°C]	Maximum [°C]
1.00E-02	-269.1	2000
1.74E-02	-127.16	2000
1.84E-02	-122.69	2000
1.94E-02	-116.27	2000
2.04E-02	-108.42	2000
5.74E-02	19.055	2000
5.92E-02	19.762	2000
6.11E-02	20.128	2000
6.53E-02	20.801	2000
7.47E-02	21.239	2000
7.73E-02	21.094	2000
7.99E-02	20.948	2000
0.97619	22.001	2000
0.98619	22.001	2000
0.99619	22.001	2000
1	22.001	2000

Table 3: Temperature for aluminum alloy

D. For Aluminum Alloy
Reaction Probe

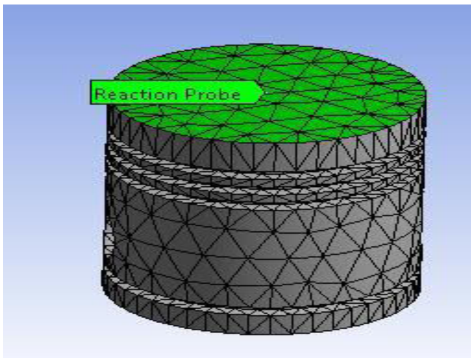

Fig 8: For Aluminum Alloy Reaction Probe

Time [s]	Reaction Probe [W]
1.00E-02	5.41E+05
1.33E-02	4.40E+05
2.94E-02	2.14E+05
3.04E-02	2.06E+05
3.14E-02	1.98E+05
4.65E-02	1.16E+05
4.76E-02	1.12E+05
4.88E-02	1.08E+05
5.00E-02	1.04E+05
5.13E-02	99988
6.98E-02	61419
7.22E-02	58308
8.87E-02	43260
9.20E-02	41306

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0.11932	31211
0.12399	30216

Table 4: Reaction Probe for aluminum alloy

E. For Aluminum Alloy

Total Heat Fux

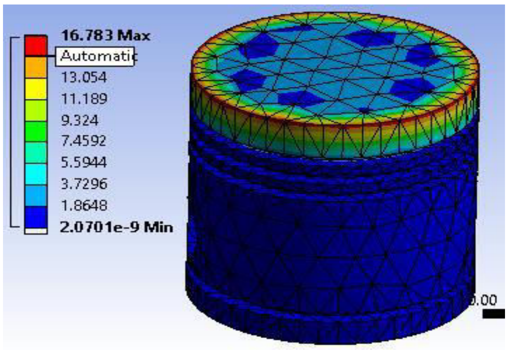

Fig 9: Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.00E-02	4.16E-09	354.8
1.94E-02	2.95E-08	197.67
2.04E-02	3.01E-08	190.27
3.84E-02	4.27E-08	123.18
3.94E-02	4.37E-08	121.13
4.04E-02	2.91E-08	119.17
5.92E-02	3.92E-08	94.739
6.11E-02	3.73E-08	93.051
7.99E-02	3.71E-09	80.926
8.28E-02	7.39E-09	79.517
9.88E-02	8.85E-09	72.725
0.10254	1.09E-08	71.416
0.29619	2.11E-09	46.705
0.98619	9.73E-07	32.738
0.99619	1.04E-06	32.669
1	1.06E-06	32.642

Table 5: Total Heat Flux for aluminum alloy

F. Cast Iron Temperature

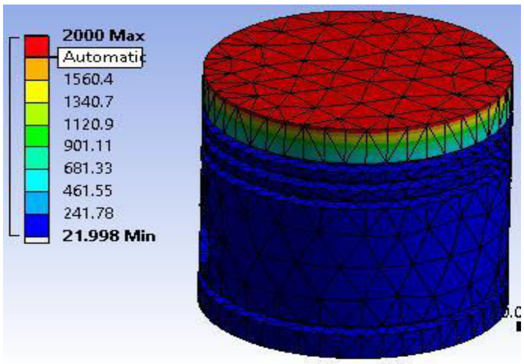

Fig 10: Temperature of Cast Iron

Time [s]	Minimum [°C]	Maximum [°C]
1.00E-02	-358.17	2000
2.61E-02	-362.4	2000
3.39E-02	-313.13	2000
9.39E-02	-89.954	2000
0.10385	-79.866	2000
0.29385	20.632	2000
0.30385	20.785	2000
0.49385	21.164	2000
0.50385	21.323	2000
0.69385	21.871	2000
0.70385	21.877	2000
0.89385	21.996	2000
0.90385	21.999	2000
0.98385	21.998	2000
0.99385	21.998	2000
1	21.998	2000

Table 6.Temperature for Cast Iron

G. *Heat Flux of Cast Iron*

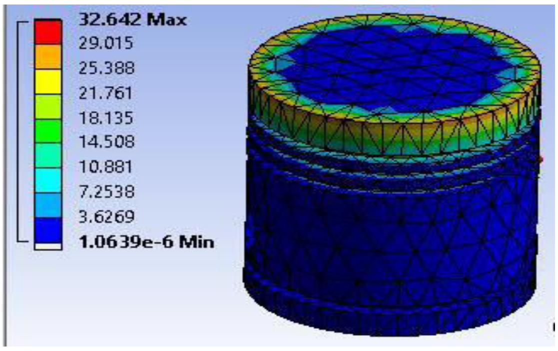

Fig 11: Heat Flux of Cast Iron

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.00E-02	1.08E-09	159.41
9.39E-02	6.76E-09	52.431
0.10385	2.75E-09	49.494
0.18385	7.20E-09	35.635
0.19385	7.40E-09	34.563
0.28385	5.19E-09	27.697
0.29385	3.97E-09	27.152
0.42385	2.96E-09	22.877
0.43385	2.39E-09	22.652
0.47385	1.96E-09	21.834
0.51385	2.63E-09	21.13
0.52385	2.82E-09	20.969
0.87385	2.43E-09	17.486
0.98385	9.46E-10	16.864
0.99385	8.40E-10	16.814
1	2.07E-09	16.783

Table 7: Heat Flux of Cast Iron

H. Reaction Probe of Cast Iron

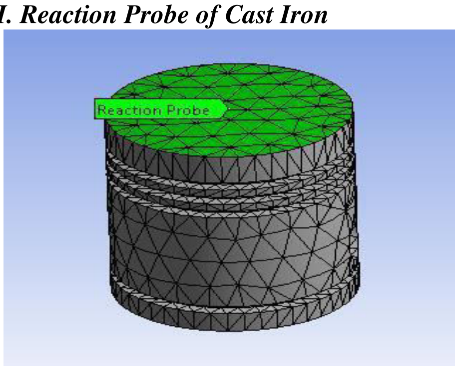

Fig 12: Reaction Probe of Cast Iron

Time [s]	Reaction Probe [W]
1.84E-02	1.90E+05
2.61E-02	1.67E+05
6.39E-02	1.10E+05
7.39E-02	99762
0.14385	55624
0.15385	51571
0.26385	25678
0.27385	24415
0.28385	23265
0.58385	11636
0.59385	11541
0.60385	11452
0.75385	10561
0.76385	10521
0.86385	10190
0.87385	10163
0.94385	9990.2
0.95385	9968
0.98385	9904.5
0.99385	9884.3
1	9872.1

Table 8: Reaction Probe for Cast Iron

VIII. CONCLUSION

The fundamental concepts and design methods concerned with single cylinders petrol engine have been studied in the results found by the use of this analytical method are nearly equal to the actual dimensions used now a days. Hence it provides a fast procedure to design a piston which can be further improved by the use of various software and methods. The most important part is that very less time is required to design the piston and only a few basic specification of the engine.

From Transient thermal Analysis we tabulated the value as below

Sr. No.	Parameter	Cast Iron	Aluminum Alloy
1	Weight	0.176kg	0.061kg
2	Volume	2.251e-005m3	2.251e-005m3
3	Total Heat Flux Generated W/mm^2	16.783	32.642
4	Reaction Probe (W)	9872.1	14709

Table 1: Conclusion

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