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DESIGN AND ANALYSIS OF IC ENGINE PISTON USING CATIA

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Abstract: *Piston is considered to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into useful mechanical power. The purpose of the piston is to provide a means of conveying the expansion of the gases to the crankshaft via the connecting rod, without loss of gas from above or oil from below. Piston is essentially a cylindrical plug that moves up and down in the cylinder. It is equipped with piston rings to provide a good seal between the cylinder wall and piston. Although the piston appears to be a simple part, it is actually quite complex from the design standpoint. The piston must be as strong as possible; however, its weight should be minimized as far as possible in order to reduce the inertia due to its reciprocating mass.*

I. INTRODUCTION

The piston is a critical part of a reciprocating engine that converts the chemical energy produced by burning fuel into mechanical effort. No fuel or oil is lost since the force of the expanding gases is transferred from the piston to the crankshaft through the connecting rod. The piston is only a plug of cylindrical material that moves up and down. To provide a snug fit between the piston and the cylinder wall, piston rings are installed. The piston may seem straightforward, but its assembly is really rather complex.

The piston's strength is essential, but it must also be as light as possible to reduce the inertia introduced by the mass of the piston as it reciprocates.

Considering the multitude of engine types and the largely different operating requirements for many applications, a great number of piston types are developed and in use today.

The most important piston types and their primary field of application shall be described as follows:

- Pistons for automotive gasoline engines (4-stroke and 2-stroke cycles).
- Pistons for automotive diesel engines.
- Pistons for commercial vehicle diesel engines.
- Pistons for locomotive, stationary and ship diesel engines.
- Pistons for motor sports.

In 2-cycle engines, mono-metal pistons of either window or full-skirt type are the standard. Dictated by the production process, forged pistons are mono-metal pistons in every case.

Aluminum materials for pistons satisfy many requirements demanded of modern pistons. The low density allows low weight and reduced mass forces of the reciprocating piston. High heat conductivity results in an acceptable temperature level, and the good strength characteristics at elevated temperatures are favorable for deformation and cracking resistance.

The *Autothermik piston* has found worldwide application in automotive gasoline engines. With the application of hydrodynamic, form of the piston skirt, the adaptability to the requirements of modern engines results in *Hydrothermal piston.* Further development to Hydrothermal *piston* is Automatize *piston*, where the heat flow from the piston top to the skirt is not interrupted since, for strength reasons, the slots in the oil ring groove were eliminated. Hydrothermal *piston* and Automatize *piston*s are predominantly used in high-powered automotive gasoline engines.

Automotive diesel engines that work according to the per-chamber, swirl chamber, or direct injection principle, operate under higher combustion gas pressures and temperatures. Load application for the first ring groove with regard to pressure and impact wear is higher than in pistons for gasoline engines. Using hyper-eutectic alloys featuring higher silicon content in the aluminum silicon alloy, the wear resistance can be increased and the heat expansion reduced for naturally aspirated engines, thus making smaller installation clearances possible. Thus, forged hyper-eutectic mono-metal pistons found widespread application in automotive diesel engines.

Pistons for commercial vehicle diesel engines:

Today, the standard design for truck diesel engines is the ring carrier piston. These pistons are produced by the gravity permanent mold casting process. The pistons are generally made of eutectic aluminum-silicon alloys. The Automatize piston was also used in air-cooled diesel engines, which were subjected to frequent cyclic load operation.

Pistons for locomotive, stationary and ship diesel engines:

Relatively low cyclic load conditions in stationary power plants, ship propulsion units, commuter rail cars and locomotive engines made the application of aluminum full-skirt pistons possible over many years.

With these pistons, the top and ring belt area is laid out rigidly and offers adequate cross-sections for heat flow. Such pistons with ring carriers and cooling coil or ring-shaped cooling galleries are either cast, or the forged piston body and the cast ring band, including the ring carrier and the cooling gallery, are welded together using the electron beam process.

Pistons for motor sports:

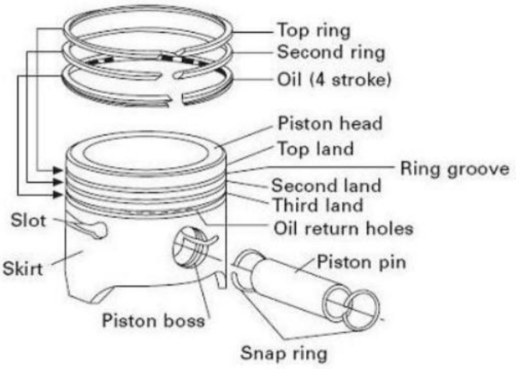
Motor sports demand and promote technical progress. Maximum wear and tear tests during motor sports yield practical results over and above the load limits of designs and materials.

The maximum power output required during motor sports stipulates lightweight high-speed engines with correspondingly high combustion pressures. For the piston, this means high strength properties and minimum weight.

II MAIN COMPONENTS OF PISTON

The important components of Piston are

shown in figure.



The most essential areas of the piston are the piston top, the ring belt including the top land, the pin support and the skirt.

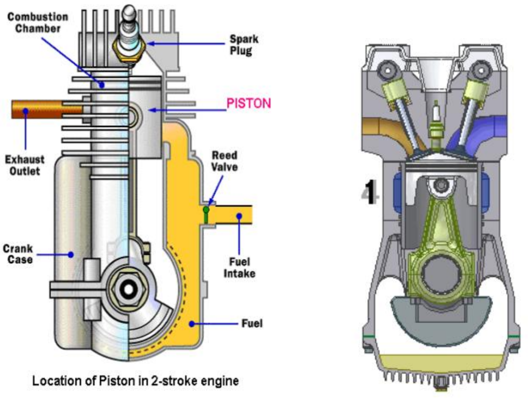
The *Piston top* is part of the combustion chamber. In gasoline engines, it can be flat, raised or recessed. In diesel engines, the combustion chamber bowl is usually located in the piston top.

The *ring belt area* usually consists of three ring grooves to accept the piston rings, whose function is to seal against gas and oil peaks. Ring lands are located between the ring grooves. The land above the first piston ring is called the top land. Two compression rings and one oil scraper ring usually constitute the ring pack.

The *Pin support* constitutes the bearing for the piston pin in the piston. It is one of the most highly loaded zones of the piston.

The *Piston skirt,* which more or less wraps around the lower part of the piston, takes up the side loads and ensures straight guidance of the piston.

The location of Piston in a two-stroke engine is shown in the following fig.



Location of Piston in 2-stroke engine

four stroke engine

Fig 1.1 Location of piston in 2 stroke and 4 stroke engine

MATERIALS FOR PISTON:

Materials used for pistons must satisfy many requirements. Besides the requirement of high strength under fluctuating temperature conditions, low specific gravity, high heat conductivity, a favorable wear characteristic and heat expansion all play an important role in determining the piston materials to be used. The material used for pistons is mainly aluminum alloy. Aluminum pistons can be either cast or forged. Cast iron is also used for piston. Aluminum is inferior to Cast iron in strength and wearing qualities, and its greater co-efficient of expansion necessitates greater clearance in the cylinder to avoid the risk of seizure.

PISTON TESTING:

The most important mission for the designer and test engineer has always been the investigation of stresses and deformations on components subjected to operating load conditions. For this, the internal combustion engine piston is a typical example.

The external forces a piston is subjected to make it evident that such a complex structure cannot be calculated easily on a piece of paper. This is why the strength-related design of pistons was for many years based on empirical development.

The two most important methods used to determine the Stress distribution and deformations on Pistons are:

Computer-aided calculations utilizing the *finite-element procedure*

Investigations of model bodies utilizing the *photo-elastic stress analysis procedure*.

In the *Finite Element method*, the model body is divided into a finite number of elements. On the junction lines, the elements are tied to the adjacent elements by nodes. Consequently, they experience uniform shifting. By connecting the equations for individual elements, a stiffness matrix for the entire body is obtained. Depending on whether high or low stresses are expected, the network can be either wide or narrow meshed.

Photo-elastic Stress analysis represents an experimental analogy method. In the case of 2-dimensional photo-elastic stress analysis method, precast plates of uniform thickness are used. From these plates, the relevant sections of a piston are produced. Under load, the occurring stresses are obtained by way of the deformation. During observation under polarized light, interference lines appear which are proportional to the stresses.

III Piston Design

As mentioned earlier, the top of the piston (the crown) is both exposed to the incoming airflow, as well as constitutes the bottom of the combustion chamber.

The piston crown during the intake stroke:

To take swirl one step further, certain piston manufacturers have equipped their pistons with swirl enhancing crown faces either equipped with circular grooves or dimpled impressions on the piston crown. These groves and dimples are designed to promote increased swirl in street engines and have been shown to further improve torque delivery by another 4 to 5% over stock figures. Similarly, high compression pistons that gain compression through a very sharp protrusion in the center of the piston will reduce disrupt swirl in the chamber and lower combustion efficiency, although the increase in compression (at 3 to 4% per added point of compression) can negate this loss.

The piston crown during the compression stroke :

This brings us to a very important point which is engine ‘squish’. The use of asymmetrical piston crown design not only continues the swirl process initiated in the intake system, but more importantly having an asymmetrical piston crown forces the air to rapidly move towards one side of the combustion chamber, especially as the piston approaches top dead center. This squish effect near top dead center can be used for several advantages:

Getting a good air and fuel mix for more efficient combustion. Moving the air and fuel mixture closer to the spark plug for easier ignition. Reducing the distance between the tip of the spark plug, and the farthest pocket of air and fuel mixture that needs to be burnt.

Reducing the flame front travel distance builds cylinder pressure faster in the chamber which reduces timing advance requirements at lower rpm, but also, maintains more torque delivery to the piston as rpm increase (and as the time that the piston spends between top dead center and 17* ATDC) starts to shrink rapidly compared to flame front travel speed past a certain rpm point, as well as for engines with a shorter rod to stroke ratio with faster piston acceleration away from Top Dead Center. Reducing the probability of detonation and uneven combustion from the better air and fuel mixture and better heat distribution.

Knowing these advantages during the compression stroke to shaping the piston top, then the typical flat top pistons of late become obviously obsolete. The best piston choice is actually a D shaped ‘reverse dome’ piston which combines an asymmetrical crown design with a thicker crown height that either mirrors the combustion chamber shape (as seen look into the bottom of the cylinder head) or with a thicker out ring on hemispherical head. The whole point here is that the air fuel charge is compressed in a tighter pocket area around the spark plug location, and moved away from the far cylinder walls. Then, to maintain the same compression ratio (even with this thicker crown height) the crown area around the spark plug is dished by the right amount to bring the total volume of the combustion chamber + the piston dish to be the correct volume for the proper engine compression ratio. Furthermore, on some applications we can take this one step further by milling down the cylinder head (or using a different cylinder head casting with shallower combustion chambers) which brings the spark plug down deeper into the bore, and offsetting the loss of combustion chamber volume with further dish in the piston crown. Bringing the air and fuel pocket closer to the spark plug, and bringing the spark plug closer to the center of the combustion chamber formed between the cylinder head contours and the piston crown contours boost engine efficiency, reduces detonation probability, reduces timing advance requirements, and promotes increased efficiencies at higher rpm as described earlier.

Finally, for a forced induced motor, care must be taken that the crown thickness after all modifications to the piston crown are complete (such as enlarging the valve reliefs for oversized valves, or increasing the piston dish for a shallower cylinder head and a lower spark plug position as described earlier) is still at least 0.175" thick with a good margin of safety being around the 0.200" mark for forged aftermarket pistons. Another thing to note is that typically enlarging valve reliefs not only reduces crown thickness as a vertical measurement, but also diagonally reduces the distance between the valve relief and the primary piston ring. This is even more evident on newer high efficiency (low emissions) engines that come from the factory with a raised primary compression piston ring (or a reduced distance / lip between the piston top and the first ring land).

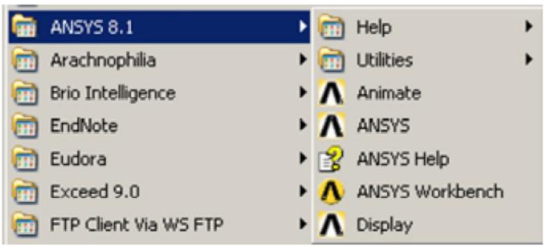
To summarize: When choosing an aftermarket piston for your motor, look for a reverse dome piston top (rather than a flat top or typical dish type piston) with dimpled flat surfaces for better mixture, and still having at least 0.2" material thickness throughout the entire crown of the piston.

If the piston I just described does not exist, a thick piston (high compression) piston can be machined down to make the piston I'm describing by someone who knows enough about this to do it properly (or by requesting a custom style piston from the piston manufacturer themselves).

IV ANSYS

Starting ANSYS:

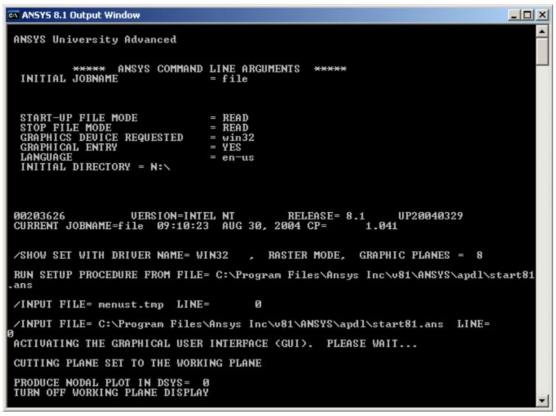
The ANSYS graphical user interface can be started by selecting the ANSYS icon located in the ANSYS 8.1 folder.



Selecting the ANSYS icon will take you directly to the graphical user interface.

ANSYS Graphical User Interface:

After starting ANSYS, two windows will appear. The first is the ANSYS 8.1 Output Window:



```
ANSYS University Advanced

        *****  ANSYS COMMAND LINE ARGUMENTS  *****
 INITIAL JOBNAME                 = file


 START-UP FILE MODE              = READ
 STOP FILE MODE                  = READ
 GRAPHICS DEVICE REQUESTED       = win32
 GRAPHICAL ENTRY                 = YES
 LANGUAGE                        = en-us
 INITIAL DIRECTORY = N:\



00203626          VERSION=INTEL NT         RELEASE= 8.1      UP20040329
CURRENT JOBNAME=file  09:10:23  AUG 30, 2004 CP=      1.041

/SHOW SET WITH DRIVER NAME= WIN32    ,  RASTER MODE,  GRAPHIC PLANES =  8

RUN SETUP PROCEDURE FROM FILE= C:\Program Files\Ansys Inc\v81\ANSYS\apdl\start81
.ans

/INPUT FILE= menust.tmp  LINE=       0

/INPUT FILE= C:\Program Files\Ansys Inc\v81\ANSYS\apdl\start81.ans  LINE=
0
ACTIVATING THE GRAPHICAL USER INTERFACE (GUI).  PLEASE WAIT...

CUTTING PLANE SET TO THE WORKING PLANE

PRODUCE NODAL PLOT IN DSYS=  0
TURN OFF WORKING PLANE DISPLAY
```

This window displays a listing of every command that ANSYS executes. If you encounter problems, this is a good place to look to see what ANSYS is doing or has done. This is one location where you will find all of the warnings and error messages that appear and the command that generated the warning/error.The second window is the ANSYS Researches graphical user interface. This is divided into 4 sections (show non next page):

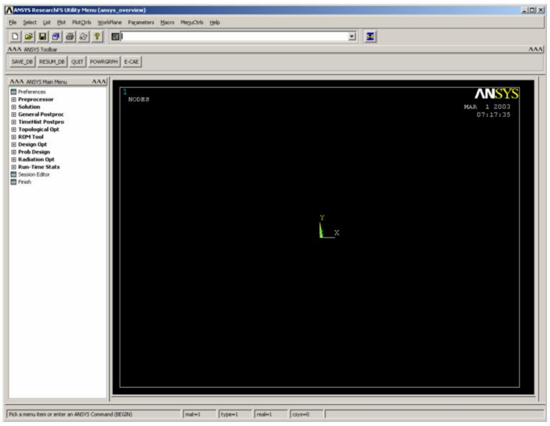
1. ANSYS Utility Menu

2. ANSYS Toolbar Menu

3. ANSYS Main Menu

4. Display window

Each section will be discussed in further detail below.



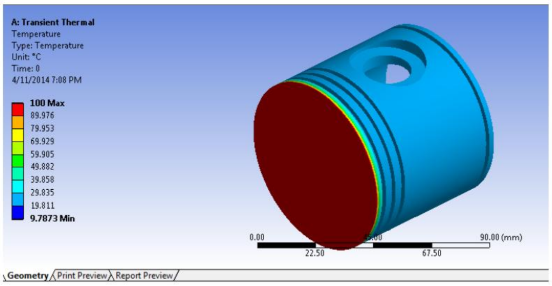
Pick a menu item or enter an ANSYS Command (BEGIN)

MATERIALS AND THEIR PROPERTIES

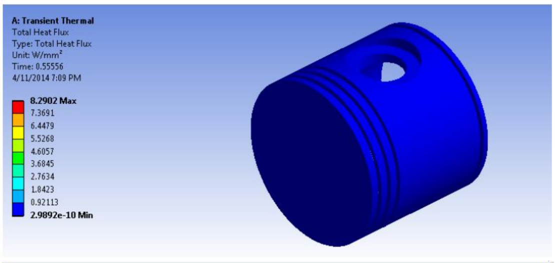
For piston:

	Al alloy 4032	AISI4340 Alloy Steel	Titanium Ti-6Al-4V
Poisson ratio	0.35	0.28	0.342
Modulus of elasticity(GPa)	79	210	113.8
Thermal conductivity (w/m k)	155	44.5	6.7
Ultimate tensile strength MPa	380	745	950
Yield tensile strength MPa	315	470	880
Density g/cc	2.68	7.8	4.43

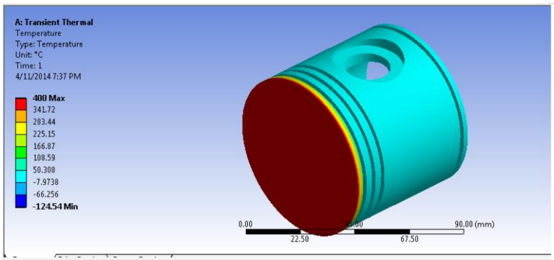
MATERIAL AL ALLOY(4032)



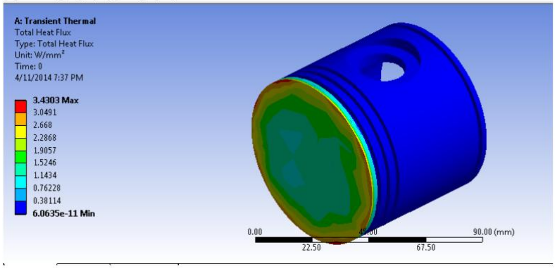
A: Transient Thermal
Temperature
Type: Temperature
Unit: °C
Time: 0
4/11/2014 7:08 PM



A: Transient Thermal
Total Heat Flux
Type: Total Heat Flux
Unit: W/mm²
Time: 0.55556
4/11/2014 7:09 PM



A: Transient Thermal
Temperature
Type: Temperature
Unit: °C
Time: 1
4/11/2014 7:37 PM



A: Transient Thermal
Total Heat Flux
Type: Total Heat Flux
Unit: W/mm²
Time: 0
4/11/2014 7:37 PM

TABLE SHOWING MIN AND MAX TEMP

AL-ALLOY(4032) MIN	AL-ALLOY(4032) MAX	Aisi4340 ALLOY STEEL MIN	Aisi4340 ALLOY STEEL MAX	TITANIUM Ti-6AL-4V MIN	TITANIUM Ti-6AL-4V MAX
9.7873	100	-6.1215	100	-8.2379	100
-5.87	200	-42.175	200	-47.005	200
-21.527	300	-78.228	300	-85.771	300
-37.185	400	-114.28	400	-124.54	400

V Results and discussion

Thermal analysis of piston shows that the value of maximum temperature is same for all the materials at the top surface of the piston crown, but minimum value of temperature in the piston made of titanium alloy. The highest value of minimum temperature is found in the piston of Al alloy. This is due to thermal conductivity of the materials. Minimum temperature is in the skirt of the piston is observed as shown in figure. Figures shows that max total heat flux is observed in piston of Al alloy and piston of titanium alloy shows the lowest value of max total heat flux along the edges.

VI Conclusion

It is concluded from the above study that using CATIAV5R20 software design and modeling become easier. Only few steps are needed to make drawing in three dimensions. Same can be imported to ANSYS for analysis. Piston made of three different materials Al alloy 4032, AISI 4340 Alloy steel and Titanium Ti-6Al-4V (Grade 5) are analyzed. Maximum temperature is found at the centre of the top surface of the piston crown. This is equal for all materials. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston and minimum in Ti alloy piston. For the given loading conditions, Al alloy piston is found most suitable. But when the loading pattern changes, other materials may be considered. With the advancement in material science, very light weight materials with good thermal and mechanical properties can be used for fail safe design of the I.C.engine. This will reduce the fuel consumption and protect the environment.

REFERENCES

1. Ajay Raj Singh et al.,, Dr. Pushpendra Kumar Sharma, ―Design, Analysis and Optimization of Three Aluminum Piston Alloys Using FEA Int. Journal of Engineering Research and Applications, ISSN : 2248-9622, Vol. 4, Issue 1 Version 3, January 2014, pp.94-102.

2. C. Kirner, J. Halbhuber, B. Uhlig, A. Oliva, S. Graf, G. Christmastime- Experimental and stimulative research advances in the piston assembly of an internal combustion engine Reprint submitted to Trichology International March 17, 2016.

3. Dilip Kumar Sonar, Madhura Chattopadhyay ―Theoretical Analysis of Stress and Design of Piston Head using CATIA & ANSYS International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319– 6726: June 2015.

4. Nunna Durga Prasanth, Dr. B Venkataraman –EXPERIMENTAL INVESTIGATION AND ANALYSIS OF PISTON BY USING HYBRID METAL MATRIX [Nunna, 4(3): March, 2015] ISSN: 2277-9655 Scientific Journal Impact Factor: 3.449 (ISRA), Impact Factor: 2.114.

5. Kethavath Vishal, Dinesh Bajaj, A.Sai Kumar-Design and Structural Analysis of Composite Piston Volume No: 2 (2015), Issue No: 10 (October) October 2015.

6. M. Srinadh , K. Rajasekhara Babu ―Static and Thermal Analysis of Piston and Piston Rings August 2015, Volume 3, Issue 8, ISSN 2349-4476.

7. Mandeep Singh, and Manish Bhargava - Analysis and Comparison of Different Materials for a Single Cylinder Four Stroke 225cc Piston using FEA Vol.6, No.4 (Dec 2016)

8. P. Arjunraj, Dr. M. Subramanian―Analysis and Comparison of Steel Piston over Aluminium Alloy Piston in Four Stroke Multicylinder Diesel Engine Volume 5, Issue 12, December 2015

9. Vaishali R. Nimbarte, Prof. S.D. Khamankar ―STRESS ANALYSIS OF

PISTON USING PRESSURE LOAD AND THERMAL LOAD‖ Volume 3, Issue 8, August 2015.

10. Mathur M.L., Sharma, A Course in Internal Combustion EngineR.P. Dhanpat Rai Publication 1997 Amitabha Ghosh, Ashok Kumar Malik, Theory of Mechanism and Machines, third Edition, Affiliated press pvt. limited New De 1998.

11. Shigley, Joseph Edward, Theory of Machines and Mechanisms, Tata McGowan Hill, New York, 2003. Khurmi, R.S. and Gupta, J.K., A Textbook of Theory of Machine,4th Edition, Eurasia Publishing House (Pvt.), Ltd, New Delhi, 2003