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# Design and Development of Piston for Steam Engine

[#1]P.B.Bhamare, [#2]P.M.Ghanegaonkar

[1]pbsquare19@gmail.com
[2]pmghanegaonkar@yahoo.com

[#1]P.G. student Mechanical Department, DYPIET Pimpri, Pune,
[#2] Professor, Mechanical Engg. Department, DYPIET, Pimpri,Pune

**ABSTRACT**

**Steam is utilized for heating in most of the process industries, due to its properties such as high latent heat, inert and cost effective. In process industries steam is normally generated at high pressure and later reduced to lower pressure through pressure reducing valve based on the process requirement. This steam can thus be utilized for generation of electricity using Heat engine.**

**Engine pistons are one of the most complex components among all the industry field components. The engine can be called the heart of car and the piston may be considered the most important part of engine. The piston is subject to large number of load cycles during its service life, hence its performance under cyclic loading and durability has to be considered in the design process.**

**This paper will mainly focus on the study of design and development of oil free piston of the steam engine for the co-generation system to provide high efficiency and performance at working. Two different design approaches are studied for oil free piston. The design of the component will be capable to carry varying load as per the loading data for a longer cycle life.**

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## I. INTRODUCTION

Steam engine is phased out of the power industry by its successor turbines and in locomotives it was replaced by internal combustion engine. The changes happen because the IC engines have more than double thermal efficiency than that of steam engine. Also the weight to power ratio is much lesser in case of IC engines which make it an excellent choice for automobiles.

As per energy tips given by Energy efficiency and renewable energy, U.S Departmental of Energy, huge potential is there for the generation of power by replacing pressure reducing valves in the process industries with the Steam Engines. Steam engines are multifuel and highly reliable as well as simple in operation and maintenance. And this makes them very important today as they were at the time of their introduction. In the process industry steam is generated at high pressure and at the user end the high pressure steam is throttled to low pressure using pressure reducing valve. Throttling destroys the potential of the steam, and this potential can be converted into electricity.

In engine, piston is one of the important components. It reciprocates within the cylinder bore by force produced during the combustion process.

The main requirements of the piston are as follows:

1. It should be oil free.
2. It should contain all the fluids above and below the piston assembly during the cycle.
3. It should transfer the work done during combustion process to the connecting rod with minimal mechanical and thermodynamic losses
4. It should aid in sealing the cylinder to prevent the escape of steam.

The piston reciprocates within the cylinder. The two extremes of this motion are referred to as Top Dead Center (TDC) and Bottom Dead Center (BDC) shown in Fig.1

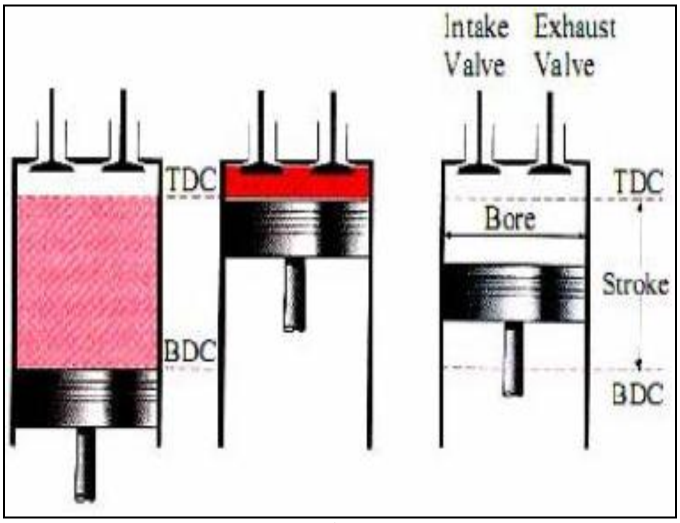


Fig.1-Cross section of reciprocating Engine

(a)Displacement (b)Clearance volume (c)Nomenclature volume

Piston damages may have different origins: mechanical stresses; thermal stresses; wear mechanisms; temperature degradation, oxidation mechanisms.[4]

Material Used

Material for the Piston will be Aluminum 6082- T6

**Table I**

**Mechanical Properties of Aluminum 6082- T6**

| *1) Mechanical Properties* | *2) Value* |
|---|---|
| *3) Tensile Strength, Ultimate* | *4) 290 MPa (Wall thickness < 5 mm)*<br>*5) 310 MPa (Wall thickness > 5 mm)* |
| *6) Tensile Strength, Ultimate* | *7) 250 MPa (Wall thickness < 5 mm)*<br>*8) 260 MPa (Wall thickness < 5 mm)* |
| *9) Elongation at break* | *10) 10%* |

Engine Pistons are one of the most complex components among all automotive or other industry field components. The piston is one of most stressed component of an entire engine. As one of main component in an engine piston technological evaluation is expected to continue and they are expected to be more and more strong, lighter, thinner and durable. [4]

To maintain the purity of steam, friction between the piston and cylinder liner cannot be overcome by oil lubrication. So here it is important to design oil free piston for Co-generation system which will provide high efficiency and performance at working.

## II. LITERATURE REVIEW

A quarter car model with sprung and unsprung mass is U.S.Department of Energy[3] According to energy tips given by Energy efficiency and renewable energy, U.S Departmental of Energy, huge potential is there for the generation of power by replacing pressure reducing valves in the process industries with the Steam Engines. Also the steam engines are multifuel and highly reliable as well as simple in operation and maintenance. And this makes them very important today as they were at the time of their introduction.

F.S. Silva [4] this work is concerned only with the analysis of fatigue-damaged pistons. Pistons from petrol and diesel engines,from automobiles, motorcycles and trains will be analyzed. Damages initiated at the crown, ring grooves, pin-holesand skirt are assessed. A compendium of case studies of fatigue-damaged pistons is presented. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work.

Mielkeet al. [5] a new piston alloy was developed by combining thechemical compositions of copper and silicon rich aluminumalloys. Copper increases fatigue strength at low and intermediate temperatures of up to 250 °C whereas the increased amount of intermetallics raises fatigue strengthat high temperature of 340 °C or beyond.Casting difficulties can be handled by grain refinement ofthe α-aluminum.

A new alloy was developed combining the alloy compositionsof the two main streams of the standard pistonalloys, i.e. the silicon rich and the copper rich piston alloy.Due to an increased amount of intermetallics this alloyshows improvements in fatigue strength of 15 % at temperaturesof 340 °C

Hisanori Koma[6]stated that increasing the quantity ofCu is effective for improving high-temperature strength, buttoo much Cu adversely affects the directionality ofsolidification and causes the final solidified portions tobecome scattered throughout the material. This facilitates thegeneration of porosity defects. With the developed material,

HisanoriKomakept Cu quantity similar to the current mass production material and alternative strengthening method described below that does not rely on Cu was considered.

HisanoriKoma contributed to mass reduction of pistons by developing a new aluminum casting material with highest level of fatigue strength. This was achieved using a development concept of creating a homogeneous structure in which Ti was added to create a fine structure and appropriate quantities of Fe and Mn were added to form a compound that is stable at high temperatures, which improves strength. Prototype test shown that the material is 14% stronger than the conventional material, which improved power of Engine and reduced mass of the piston.Manufacturing cost for the piston is taken care by using gravity casting.To ensure the castability of the new alloy, composition design also considered the fluidity of the material.

 

Kei Nakayama et al. [7] Offsetting the crankshaft axis with respect to the cylinder axis has been thought to be a method to reduce piston side force. Kei Nakayama modified a single-cylinder engine to have a crankshaftoffset. Piston frictional force was measured in real-time by using a floating liner method. In addition, laser induced fluorescence (LIF) technique was employed to measure oil film thickness on the piston skirt area, and a gap sensor was used to measure piston motion. As a result, the authors concluded that the effect of crankshaft offset on piston friction could not be explained only by its effect on the piston side force. In accordance with the measurement results, crankshaft offset changed piston slap motion. Hence, the conditions of piston skirt contact and oil film development changed in addition to the change in the piston side force and affected the piston friction characteristics.

G. Nicoletto[8] an extensive fatigue testing program of eutectic Al-Si alloys at room temperature and at several high temperatures (250 °C, 300°C and 350°C) is reported. Specimens were extracted from piston crowns and tested in a rotating bending test machine. The resulting fatigue strength loss at 107 cycles is quantified by a staircase approach.

Al-Si alloys specifically developed for piston production are tested at room temperature and at several high temperatures in the range 250 to 350°C. Specimens were extracted by actual pistons and tested a rotating bending test machine equipped with an oven. The resulting fatigue strength loss at 107 cycles is quantified by a staircase approach. The influence of alloy composition and piston production route are investigated on the high temperature high cycle fatigue strength.

James W. Winship[9] the purpose of this paper was to aid engine designer to choose the type of the piston which will fill his particular requirement. This paper is designed to aid and guide the automotive engine designer in selecting a piston design capable of performing satisfactory requirements. Design parameters relative to clearances, strength, heat flow, and controlled expansion are considered.

Author explained different types of the piston and their expansion control to maintain a good running fit at operating conditions, and this tight running fit results into minimum skirt wall thickness because of decrease in corner loading. He described four types of the pistons; Expansion controlled Strut Piston, Closed Type Expansion Controlled Strut Piston, Closed Slotless Type Strut Piston, Al-Aluminum Pistons Open and closed. Advantages, disadvantages and suitability of each type is explained by James.

According to him Initial piston drawing establishes desired diameter, compression height, number and size of rings, width and length of connecting rod, and enough outlines of the crankshaft and its counterweights to establish their profile, width, and relation to centerline of bores.

D. G. Wallace [10] stated that the cause of High blow-by and high oil consumption in IC Engine is failure in the Piston ring, Piston, and cylinder combination. He explained all the possible cause for high blow-by and high oil consumption which are as follows,

1) Improper ring installation
   a) Compression ring installed upside down
   b) Incorrect width of compression rings
   c) Incorrect width of oil rings
   d) Incorrect diameter of rings

2) Abnormal Piston wear patterns
3) Compression ring sticking
4) Top groove wear and top ring brekage
5) Overall ring, piston, and cylinder wear: abrasive wear, scuffing and scoring, and corrosive wear.

In engines with pressurized intake and exhaust system, excessive valve guide clearances can cause high blow-by, which in turn can cause excessive external leakage.

Jean-Louis Ligieret al.[11] studied the tribology in piston pin. The general behavior of the piston pin is described. The oil film thickness variations during cycle are described and the critical phases are shown. Several parameters like pin diameter, temperature, pressure-viscosity coefficient have been investigated in order to understand their influence. A wear model for bearings located on the piston pin is built with the special emphasis on asperity contacts.

Jean-Louis Ligier pointed out the severities of operation of piston pin bearings, as well as some of the specific characteristics of the functioning of this type of bearing. The most noteworthy of these specific characteristics are that these bearings essentially operate in a hydrodynamic mode, very infrequently in a mixed lubrication mode, and that the rotation of the piston pin is different from that of the conrod.

Suryannarayna [12] the prior work in labyrinth seals has been discussed in detail by him. He did the detailed study of various labyrinth seal based upon FLUENT CFD simulations, studies the influence of flow parameters, in addition to geometry, on the carry over coefficient of a cavity, developing a better model for the same. On basis of all analytical study he validated the leakage model against CFD and prior experimental results.

Stoloda [13] was another early researcher of labyrinth seal leakage. He mentioned that the mass flow rate is inversely proportional to the square root of the number of teeth.

## III. CRITICAL AREAS IN PISTON

1. Piston head
2. Piston pin holes
3. Piston compression ring grooves

Although stresses on pistons change with piston geometries and engine pressures, Figs. 2 and 3 show a typical stress distribution on an engine piston.

It is clear that there are mainly two critical areas: the top side of piston pin hole and two areas at the piston head. Stress analyses on diesel pistons show the same critical areas.

*Piston head and piston pin hole*

As observed in Figs. 2 and 3, due to the pressure at the piston head, there are mainly two critical areas: piston pin holes and localized areas at the piston head.

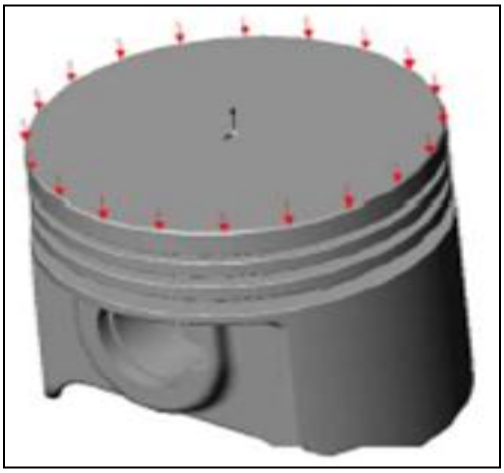

Fig.2 Pressure at the piston head area [4]

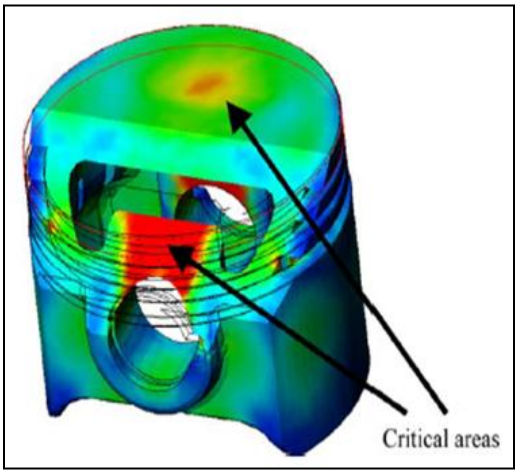


Fig.3 Typical stress distribution on anengine piston [4]

The crack always initiated at the same vertical plane that contains the pin holes. The stresses at the piston head are higher at those areas.

*Piston compression grooves*

Typical fatigue damage occurs on piston compression grooves. Fig. 4 shows one damaged piston.
It is clear by Fig. 4(b) that the mechanism is fatigue. The striations clearly show the propagation of the crack. In Fig. 5(a) simulation is made for stress analysis in piston grooves.
It is clear that there is a stress concentration on a stress radius of the groove when the compression ring is not inside the groove – the inner side of the ring is located at mid distance of the groove depth.
For a comparison, a simulation of the maximum Von Mises stress with the ring inside the groove (close to the piston wall) presented a maximum stress of about one third of the one shown in Fig. 5(b), where the inner side of the ring is located at mid distance of the groove depth. Thus there is an exponential growth of the stress when the distance between the ring and the piston wall increases. The same is to say that there is an increase in the stress at the piston groove when the clearance between the piston and the cylinder increases.

Fig. (a)

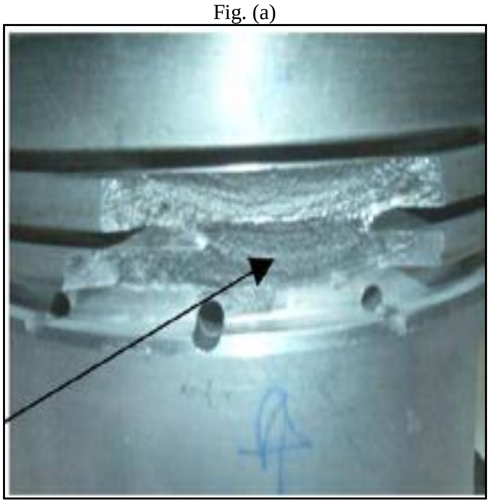

Fig. (b)

Fig.4 Engine piston with damaged grooves: (a) piston; (b) detail of damaged grooves. [4]

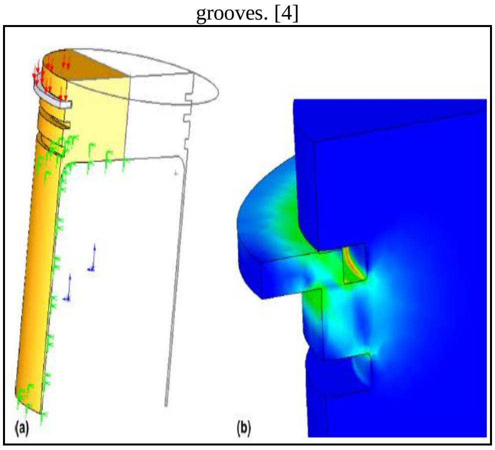


Fig.5Typical stress distribution on stress radius on the grooves [9]

## IV.METHODS ADOPTED FOR OIL FREE PERSON

### A. *Ring Piston*

In order to improve the sealing behavior of the compression rings, rings are preloaded. As a result piston rings are pressed against the liner surface.
Piston and piston rings move on the surface of the liner, to avoid wear the demands to the surface quality are high, meaning the shape, the roughness and the hardness

 

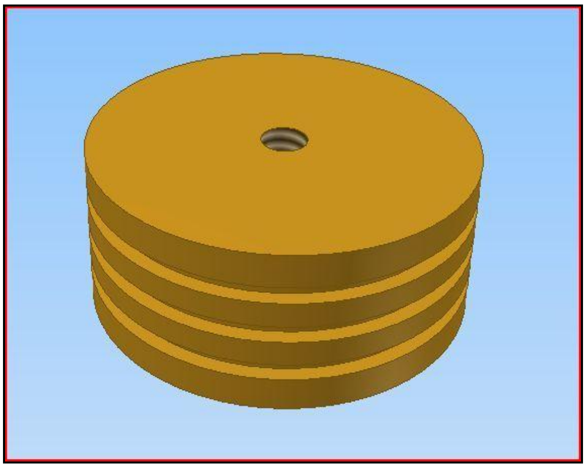

Fig. 6 Ring Piston

Fig.7 Piston Rings

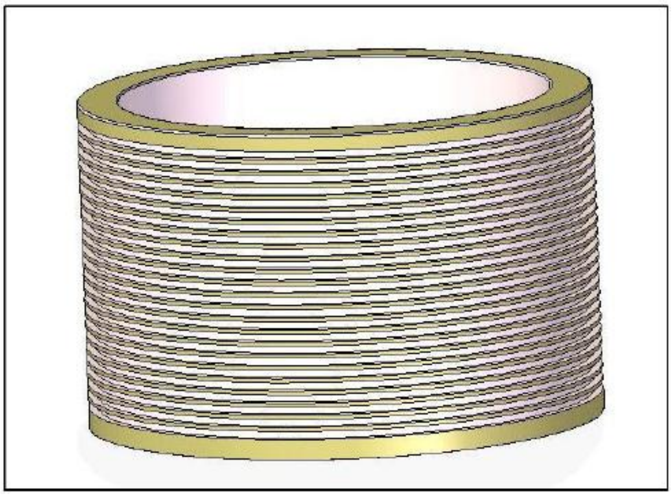

Fig. 8 Piston with labyrinth seal

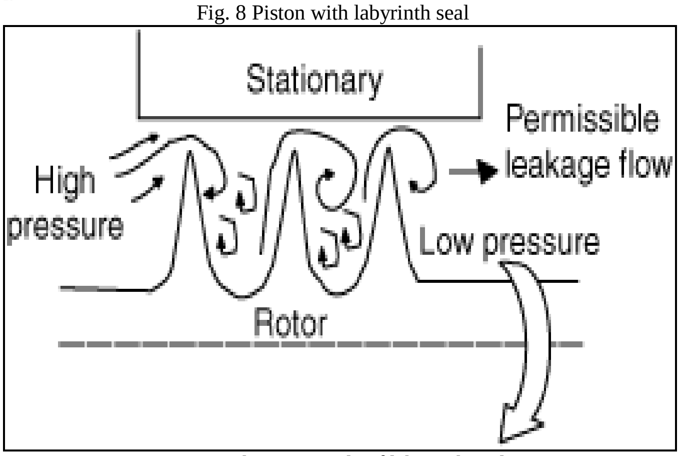


Fig. 9working principle of labyrinth seal

### B. *Labyrinth seal*

Labyrinth seal is one of the popular seal designs and widely used in oil free compressors and other application like turbine, where a small amount of internal leakage is allowable. As for any seal, the purpose of the labyrinth seal is to reduce the internal leakage of fluid flow by killing the pressure in between seal grooves increasing the friction to fluid flow in the leakage path by dissipating as much of the kinetic energy of the leakage flow jet as possible. For labyrinth seals, the energy dissipation is achieved by a series of constrictions and grooves. When the fluid flows through the constriction (under each groove), a part of the pressure head is converted into kinetic energy, which is dissipated through small scale turbulence-viscosity interaction in the grooves that follows. This increases the resistance to flow as compared to a smooth seal.

#### 1) *Effect of Clearance on leakage*

Labyrinth seal is non-contact type of seal, hence some gap always presents between seal and inner wall of cylinder, this gap is called as clearance. Clearance has most significant effects on the leakage; from the graph shown below we can see that leakage is linearly increasing with increase in clearance. This graph has been plotted for leakage against various clearances. Since we are studying the significance of clearance on leakage; leakage is calculated by considering the same seal geometry with clearance as variable. To minimize the leakage, clearance need to keep as tighter as possible.

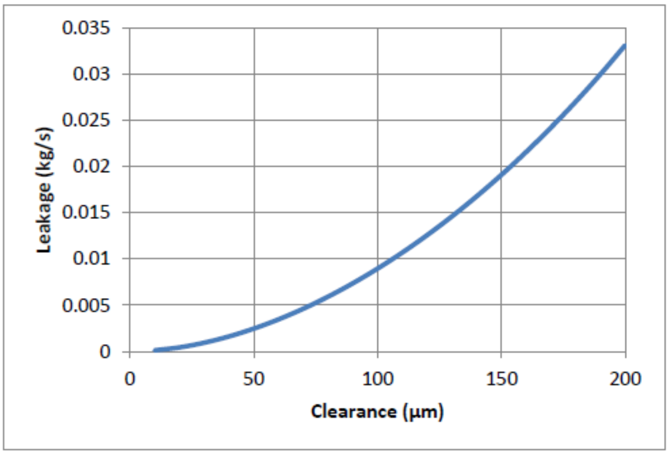


Fig. 10 Effect of clearance on leakage flow

*2) Effect of number of tooth on leakage*

Number of tooth has significant effect on leakage flow. Leakage flow is inversely proportional to square root number of tooth, this relation between leakage and number of tooth was given by Stoloda[13]. This relation shows the parabolic nature of curve as shown in fig 11. This graph is plotted for leakage against number of tooth. It can be seen from graph, as the number of tooth increases in seal; leakage through the seal gets decreases.

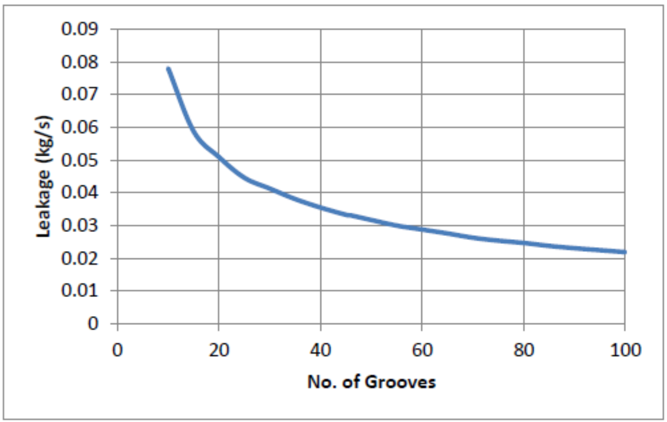


Fig.11Effect of number of grooves on leakage flow

*3) Effects of Tooth Thickness on leakage*

If one does analytical study of effect of tooth thickness by using any leakage model, then it will show that; increase in tooth thickness there is small increase in leakage same as shown in figure12. Graph shown below is plotted for two types of seals which differ only in tooth thickness and all other geometric parameters and boundary condition are same. But experimentally it is found that, up to a certain point increase in tooth thickness resulted small drop in leakage and after that if one keeps on increasing tooth thickness leakage also increases. This small decrease in leakage was possibly because of increased in frictional losses and this increase in friction may be because of longer constrictions.

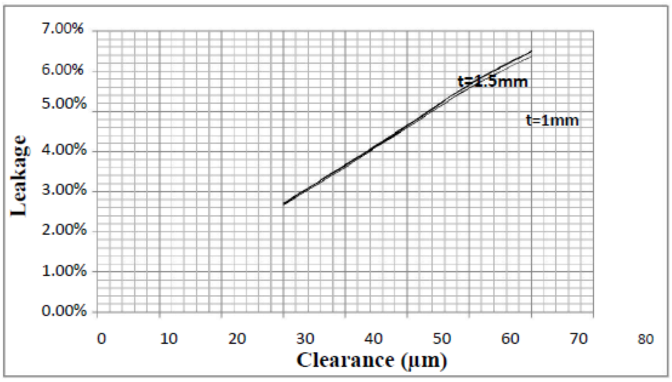


Fig.12Effect of tooth thickness on leakage

*4) Effects of tooth pitch on leakage*

This ratio has significant effect on leakage, but secondary to that of clearance. Fig 13 shown below is plotted for leakage flow against variable tooth pitch/thickness ratio by keeping other geometric parameter and boundary condition constant. From this fig. it is observed that initially for lower ratio leakage is higher and as pitch/thickness ratio increases leakage decreases. But if you see the graph, one thing can be easily analyze that; after pitch/thickness ratio 3 curves start to get flatten. So there won't be any further decrease in leakage if one keeps on going for higher ratio. Another thing is that this parameter is constrained by space limitation, so value of ratio is depend on the application for which you are designing the seal.

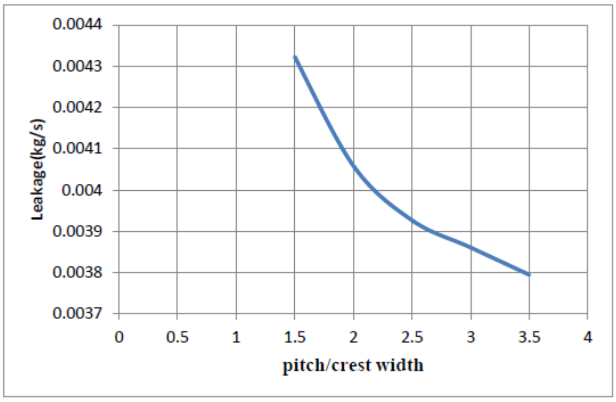


Fig.13Effect of pitch/crest width on leakage

*5) Effect of groove depth on leakage*

There is no equation developed to find out the effect of depth of groove. Gamal [14] explain the effect of groove on the basis experiments done by him. He conducted some test to determine the effect of cavity depth and it showed that this design parameter had close to no impact on the leakage through the seal. A trend was observed that indicating that the leakage through the seal could be reduced slightly by making the cavities deeper, but the effect was close to inconsequential at the test supply pressures. Installing the cavity insert corresponded to an 80% reduction in cavity depth, only led to increases in leakage rates of less than 1% for most supply pressures and less than 5% for the highest changes at the lowest supply pressures.

## V.CONCLUSION

In the process industries pressure reducing valves can be replaced by steam engines to conserve the energy and to reduce the steam pressure for the process requirement.For steam Engine oil free Piston Design can be done by using Labyrinth seal or by changing the material of piston ring to PEEK.

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