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**Research Article**

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# Computation of the Relationship between the Piston Ring Axial Thickness and Ring Gap

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**Abstract** An internal combustion engine is one in which combustion of mixture (air-fuel) burn internally. It contain different parts which are to relate together to have required engine efficiency. Among these parts is the piston which contains the piston ring that maintains a perfect seal between the cylinder wall and the piston. The dimensional relationships of the piston rings determines the degree by which they seats in the groove of the piston thereby determine the efficiency of the compression of the engine which affects the output of the engine. Visual basic computer code was developed for computation of piston ring axial thickness corresponding to the piston ring gap. Aided by the developed software, the relationship between piston ring axial thickness and piston ring gap was computed. Results obtain for case studies examined by varying the angular coordinate of the ring, showed that piston ring gap increases with piston ring axial thickness. The numerical results were processed with the Microsoft Excel package, which yield a relationship of the form, $S = a + bt_a$ where a, and bare real characteristic values of a particular problem.

**Keywords** Internal Combustion Engine, Piston Ring, Compression Ring, Piston Radial Thickness, and Angular Coordinate

## Introduction

Automobile according to Rajput [1] is a self- propelled vehicle driven by internal combustion engine that is used for transportation of goods and passenger from one place to another. Almost all automotive engines are internal combustion engine and of the reciprocating type (piston engine). They are the source of power that makes the wheels go round thereby moving the vehicle on the earth. According to Banga and Singh [2]; Salami [3] as reported by Lateef and Kareem [4], the burning of fuel inside the engine produces high pressure in the engine combustion chamber. Automotive engine consist of many important parts vis-a-vis cylinder head, cylinder block, piston and its rings, crankshaft, camshaft, tappet, flywheel e.tc.

A piston is fitted to the cylinder as a face to receive gas pressure and transmit the thrust to the connecting rod. The piston must be a fairly loose fit in the cylinder to avoid sticking tight due to expansion as a result of heat and the clearance between the piston and cylinder walls must not be too much to avoid leakages of oil and pressure [5]. The piston ring is one of the main components of an internal combustion engine. Its main purposes are to seal the combustion chamber of the engine preventing loss of the pressure, minimize the friction against the cylinder liner but also transfer heat from the piston to the cooled cylinder liner. Another important property of the piston ring is to evenly distribute oil along the cylinder liner in order to avoid engine seizure [6]. It also distributes axial and radial stress evenly which is a function of its radial thickness, axial thickness and piston ring gap.

Piston rings for current internal combustion engines have to meet all the requirements of a dynamic seal for linear motion that operates under demanding thermal and chemical conditions. In short, the following requirements for piston rings can be identified:

- Low friction, for supporting a high power efficiency rate
- Low wear of the ring, for ensuring a long operational lifetime
- Low wear of the cylinder liner, for retaining the desired surface texture of the liner
- Emission suppression, by limiting the flow of engine oil to the combustion chamber
- Good sealing capability and low blow-by for supporting the power efficiency rate
- Good resistance against mechano-thermal fatigue, chemical attacks and hot erosion

Reliable operation and cost effectiveness for a significantly long time [7].

The main task of compression rings is to prevent the passage of combustion gas between piston and cylinder wall into the crankcase. For the majority of engines, this objective is achieved by two compression rings which together form a gas labyrinth. For design reasons, the tightness of piston ring sealing system in combustion engines is below 100%; as a result a small amount of blow-by gases will always pass by the piston rings in to the crankcase. This is however, a normal state which cannot be completely avoided due to the design. It is essential though, to prevent any excessive transfer of hot combustion gases past the piston and cylinder wall, there should be a relationship between piston dimensions and piston rings dimensions with the wall of the cylinder. Otherwise this would lead to power loss, an increase of heat in the components as well as a loss of lubricating effects. The service life and the function of the engine would consequently be impaired. The piston rings are also used to control the oil film. The oil is uniformly distributed on to the cylinder wall by the rings. Most excess oil is removed by oil control (3rd ring), although the combined scraper-compression rings (2nd ring) removes the oil.

Although the construction of piston compression rings are simple, they perform a good number of tasks during engine operation among which tightness of combustion chamber according to Wojcieeh and Piotr [8] seems to be the most important one. A correct designed of piston- cylinder assembly relationship should adjoin cylinder liner with its entire circumference, although, due to many factors like cylinder wear, liner fittings deformation, incorrect fittings of piston compression ring e.t.c the circumferential contacts of ring and liner (though compensated to certain degree)efficiency begin to decrease. Due to this imperfect contact between the liner and circumferential contact of the ring and piston, which result to increase in oil consumption and fall of engine power there is need to find out the actual relationship among the dimensions to have the needed efficiency.

Gas leakages from piston-rod sealing system are usually under critical observation, their rate being closely monitored, whereas gradual drops in flow rate often remain unregistered, or are tolerated until their consequences assumed significant proportions. Parameters of compression ring are as follows: external ring diameter d (equal to the liner diameter), radial thickness gp, axial height hp, distance between ends of ring free shape m and ring gap when in cylinder lz (Fig. 1).On the other hand tangential and radial force, Ft and Q respectively (Fig. 1) and circumferential pressure p (Fig. 2) as well which are related to the modulus of elasticity E are used for evaluation of ring elastic properties [8].

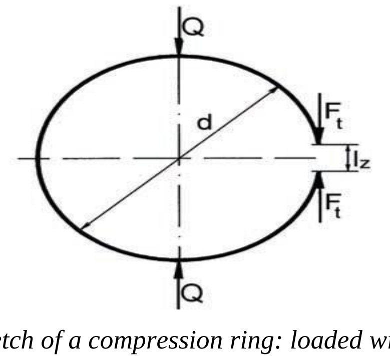


*Figure 1: Sketch of a compression ring: loaded with force Ft [8]*

Furthermore, according to Richard and Albin [9], advances in modern engine development are becoming more and more challenging and demand researching into. The intense increase of thermal and mechanical loads interacting in the combustion chamber as a result of higher power density requires perfecting the function of piston rings especially with regard to emission reduction technology. Gas and friction forces not only create axial forces but also moments based on the piston ring center of mass. They further explain that, the motion of the ring starts when the resulting axial forces change directions and can no longer overcome the moments acting on the ring and in the same way the ring motion ends when the resulting axial force becomes high enough to overcome the moments acting on the ring sufficiently to force the position of the piston ring to the opposite side Hence the change of position of a piston ring is not a sudden effect, but more a process which can possibly last 60 degrees of crank angle or more. There are also movements where the change of position starts, but full contact on the opposite side of the groove cannot be achieved. In these cases the piston ring can no longer create a seal against the ring groove flank and the combustion gas can pass around the back of the piston ring (this can occur both on the bottom side and top side). This has a significant effect on blow-by.

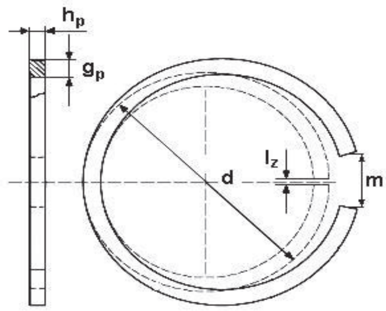


*Figure 2: Sketch of a compression ring: exemplary picture of uniform wall pressure distribution [8]*

The pressure of the piston ring at any point of its perimeter may be described by the equation [10]

$$P = P_a(1+0.42Cos2\theta - 0.18Cos3\theta) ------1$$

Where, $P =$ Radial Pressure on the ring

$P_a$ =Average pressure of the ring

$\theta$ =The angular coordinate of the point in the polar coordinate system

The shape of the free ring which ensures the pressure distribution described by the above equation is expressed as;

$$S = \frac{36\pi P_a r^4}{E t^3} ---------2$$

Where, $S =$ Piston ring gap

$E =$ Young modulus of the piston material

$t =$ Piston radial thickness of the ring

$r =$ Mean radius of the ring

Bending stress created in the cross section of the opposite to the joint is expressed [Khovakh, M. et al (1977)] as;

$$\sigma = 0.382E\frac{S}{D(B-1)} ---------3$$

Where, $\sigma =$ Bending stress

$D =$ Diameter of the cylinder bore

$B =$ Ratio of cylinder diameter and radial thickness of the ring (D/t)

The relationship between the cylinder diameter and ring mean radius is given as;

$$D = 2r ------------4$$

From equation a (1)

$$P_a = \frac{P}{[1 + 0.42Cos2\theta - 0.18Cos3\theta} - - - - - 5$$

Also, from equation (2)

$$r = \frac{1}{3.26}\left(\frac{SEt^3}{P_a}\right)^{0.25} - - - - - - - - - - 6$$

And from equation (3)

$$D = \frac{0.382ES}{(B-1)\sigma} - - - - - - - - 7$$

Put equation (6) into equation (4)

$$D = 0.6135\left(\frac{SEt^3}{P_a}\right)^{0.25} - - - - - - - - 8$$

Consider equation (8) and equation (7)

$$t = 0.532\frac{ES\,P_a^{\;0.3}}{[(B-1)\sigma]^{1.3}} - - - - - - - - - - 9$$

Resolving equation (5) and (9) gives

$$S = \frac{t[\sigma(B-1)]^{1'3}[1+0.42Cos2\theta - 0.18Cos3\theta]^{0.3}}{E\,P^{0.3}} 10$$

The radial thickness (t) relationship with the axial thickness of the ring is expressed as- t = $t_a$/0.7.

Therefore,equation10become:

$$S = \frac{\left(t_a/0.7\right)[\sigma(B-1)]^{1'3}[1+0.42Cos2\theta - 0.18Cos3\theta]^{0.3}}{E\,P^{0.3}} - -11$$

The value of piston ring axial thickness ($t_a$), piston gap (S) radial pressure on the ring (P), the ratio of cylinder diameter and piston ring radial thickness (B) and angular coordinate of the point in the polar coordinate system ( $\theta$) all distinct features of design condition for piston compression ring efficiency in the automobile engine. Therefore, if the radial pressure on the ring, young modulus (E), the ratio of cylinder diameter and the angular coordinate are held constant, the relationship between the piston ring radial thickness and piston ring gap can be deduced from equation (11).

Computer simulation of equation (10) was carried out, the program structured in interactive data input form was developed in VISUAL BASIC. The software determines the effects of increasing the piston ring radial thickness on the piston ring gap of an internal combustion engine. Data generated from the program were further process with EXCEL PACKAGE to obtain mathematical expressions which describe the relationship between piston ring radial thickness and piston ring gap.

**CASE STUDY**: A typical case study (A) with the following parameter was investigated,

$t_a = 0.001701m$, $\sigma = 290MN/m^2$, $B = 20$, $\theta = 15^0$, $P = 70KN/m^2$, $E = 207GP_a$

Keeping all the parameters constant, the piston ring axial thickness (t) was varied between 0.001701 to 0.004851m resulting in different piston ring gap. Also, for cases B, C, D and E using are increasing in angular coordinate of $5^0$ and with variation of piston ring axial thickness to yield different piston ring gap result.

**Results and Discussion**

Table 1 presented the result obtained from the piston ring gap increases with increase in piston ring axial thickness. Also, increase in angular coordinate at constant piston ring axial thickness leads to increase in the piston ring gap. Accordingly, the data of the output of the computer program (Table 1) were further processed with EXCEL package to develop a mathematical relationship between piston ring gap and piston ring axial thickness of internal combustion engine. As evident from Figure 3 and4, the cases considered (A-E) gave quantitative expression in respective order with each having $R^2$ value of 1. Generally, these relationships are linear and of form: $S = a + bt_a$ as presented below:

$$S = 96542 + 13597t_a$$

$$S = 86905 + 12240t_a$$

$$S = 67871 + 9559.4t_a$$

$$S = 56702 + 7986.3t_a$$

$$S = 68999 + 9718.2t_a$$

$$S = 59676 + 8405.1t_a ,$$

Where *a*, and *b* are real characteristic values of the particular problem of compression in an internal combustion automobiles engine piston, piston rings and cylinder relationship. It can thus be deduced that larger piston ring gap requires corresponding larger piston ring axial thickness in agreement with a linear relationships that boost sealing and compression efficiency of automobile engines. The correlations above are for the specific cases considered. An attempt to obtain a single correlation to generalize the relationship between piston ring gap and piston ring axial thickness using line of best fit (Figure 5) generated an approximated linear function ( $S = a + bt_a$ )which indicates that increase in axial thickness leads to increase in piston ring gap:

**Table 1**: Program Output for Piston Ring Axial Thickness with Piston Ring Gap at Varying Angular Coordinate

| S. No. | Piston Axial Thickness | Piston Ring Gap | | | | | |
|---|---|---|---|---|---|---|---|
| | | CASE A ($\theta = 15^0$) | CASE B ($\theta = 20^0$) | CASE C ($\theta = 25^0$) | CASE D ($\theta = 30^0$) | CASE E ($\theta = 35^0$) | CASE F ($\theta = 40^0$) |
| 1 | 0.001701 | 110139.47 | 99145.50 | 77430.84 | 64688.76 | 78717.35 | 68081.54 |
| 2 | 0.001911 | 123736.93 | 111385.68 | 86990.21 | 72675.03 | 88435.86 | 76486.67 |
| 3 | 0.002121 | 137334.40 | 123625.87 | 96549.57 | 80661.30 | 98154.09 | 84891.80 |
| 4 | 0.002331 | 150931.86 | 135866.05 | 106108.94 | 88647.57 | 107872.31 | 93296.93 |
| 5 | 0.002541 | 164529.33 | 148106.24 | 115668.30 | 96633.83 | 117590.54 | 101702.06 |
| 6 | 0.002751 | 178126.79 | 160346.42 | 125227.66 | 104620.10 | 127308.77 | 110107.19 |
| 7 | 0.002961 | 191724.26 | 172586.61 | 134787.03 | 112606.37 | 137026.99 | 118512.32 |
| 8 | 0.003171 | 205321.72 | 184826.79 | 144346.39 | 120592.63 | 146745.22 | 126917.45 |
| 9 | 0.003381 | 218919.19 | 197066.98 | 153905.75 | 128578.90 | 156463.45 | 135322.58 |
| 10 | 0.003591 | 232516.65 | 209307.16 | 163465.12 | 136565.17 | 166181.67 | 143.727.70 |
| 11 | 0.003801 | 246114.12 | 221547.35 | 173024.48 | 144551.44 | 175899.90 | 152132.83 |
| 12 | 0.004011 | 259711.58 | 233787.53 | 182583.84 | 152537.70 | 185618.13 | 160537.96 |
| 13 | 0.004221 | 273309.05 | 246027.72 | 192143.21 | 160523.97 | 195336.35 | 168943.09 |
| 14 | 0.004431 | 286906.51 | 258267.90 | 201702.57 | 168510.24 | 205054.58 | 177348.22 |
| 15 | 0.004641 | 300503.98 | 270508.09 | 211261,93 | 176496.50 | 214772.81 | 185753.35 |
| 16 | 0.004851 | 314101.44 | 282748.27 | 220821.30 | 184482.77 | 224491.03 | 194158.48 |

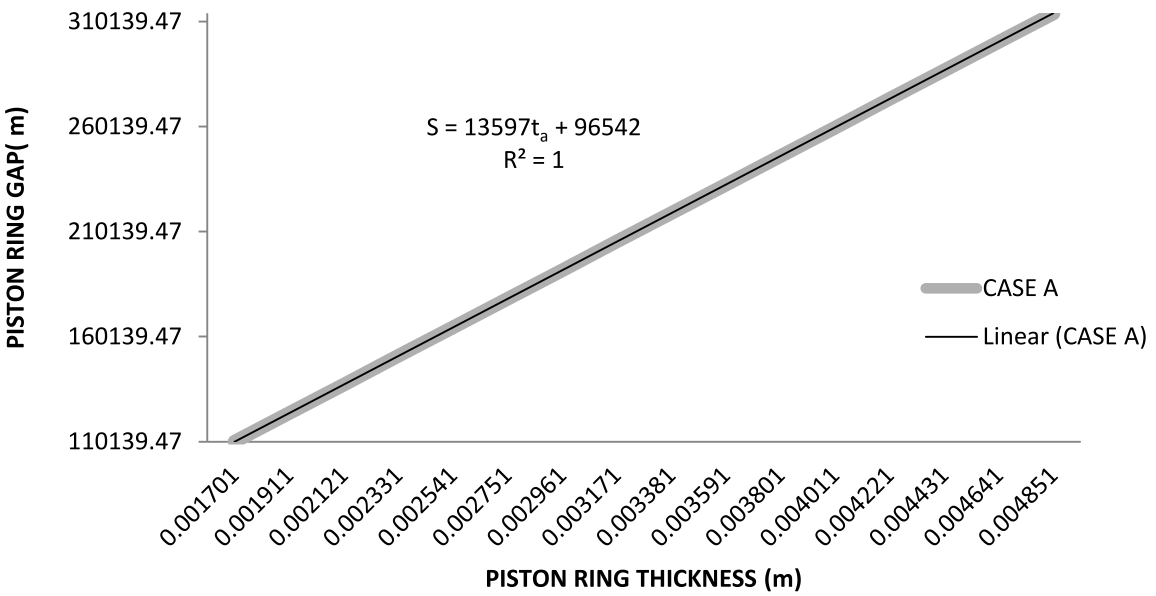


*Figure 3: Piston Ring Radial Thickness Variation with Piston Ring Gap (CASE A)*

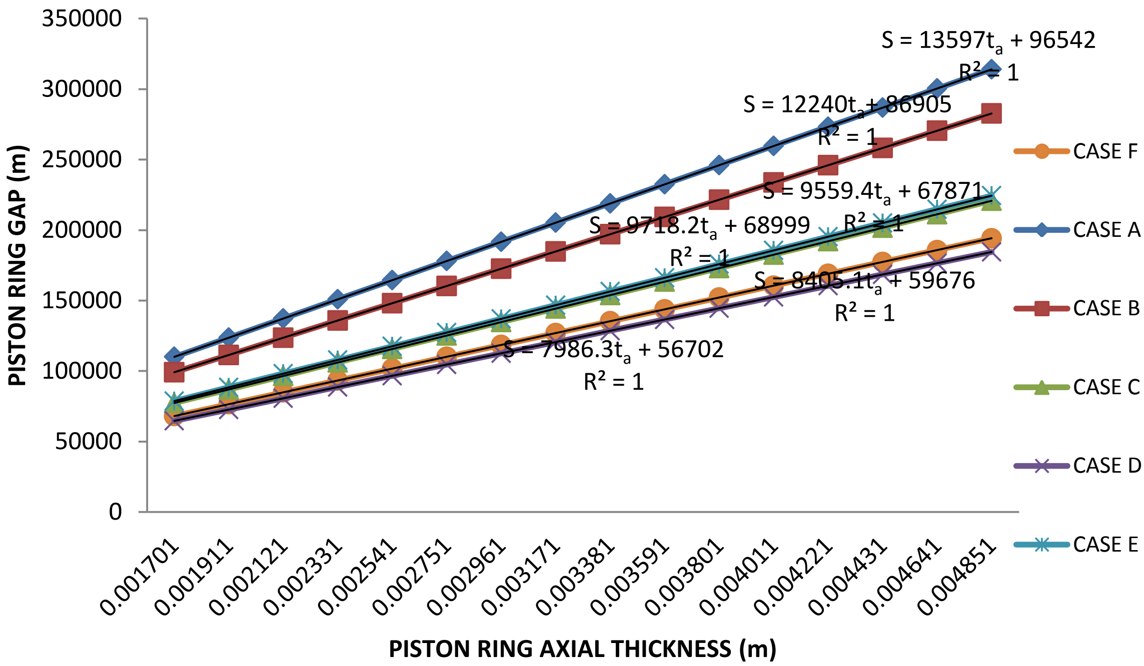


*Figure 4: Relationship between piston ring axial thickness and piston gap at varying angular coordinate*

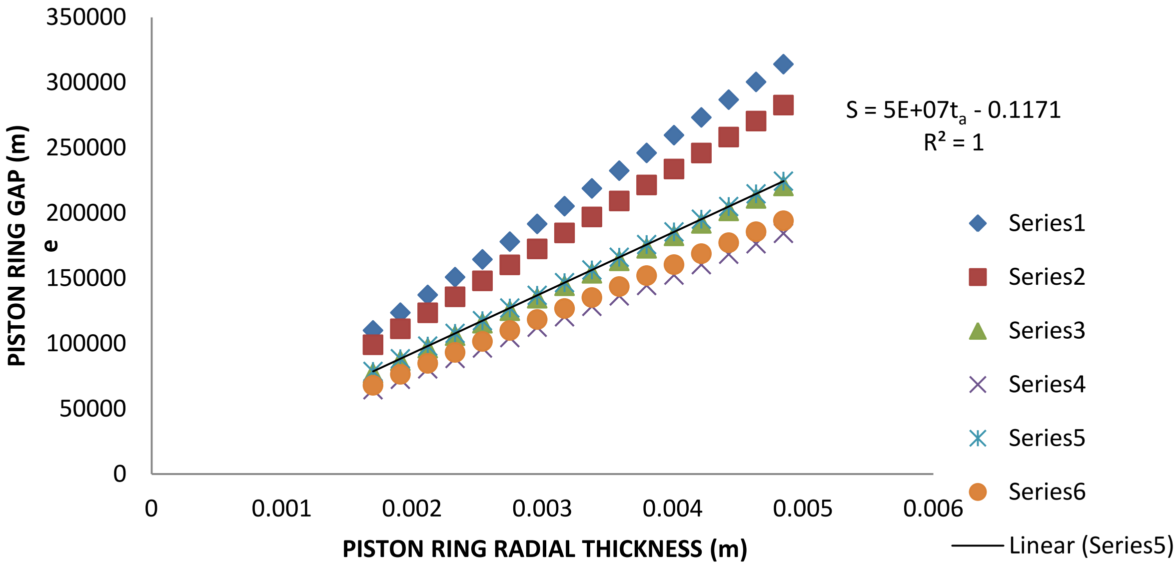


*Figure 5: Variation of piston radial thickness with piston gap at different coordinate angles*

**Conclusion**

The paper discusses the relationship between the piston ring axial thickness and piston ring gap for an effective sealing of the pressure developed in the motor vehicle engine. A computer program is developed to evaluate the relationship and conclusion is made. The results confirm that increase in the piston ring axial thickness leads to increase in piston ring gap. Further analysis showed that piston ring axial thickness increases linearly with piston ring gap, and conclusively, for a perfect mathematical relationship and also for part replacement between piston ring, Piston and cylinder with respect to Angular coordinate of the piston ring, a linear equation resulted: $S = a + bt_a$ with *a and b* been a real value characteristic dependent of specific Angular coordinate.

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