Cylinder's liner wear comparison between inline, offset and twin crankshaft Internal combustion engines

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مستخلص

التآكل الذي يحدث في اسطوانات الحركات يحدث تشويهاً في مبطّنِ الأسطوانة. هذا التشويه يُؤدّي إلى تقرّب الضغط منِ داخل الأسطوانات و من ثم فقدان في القدرة. أي بمعنى آخر تقليلِ كفاءةِ محرّكِ.

قوة الدفع الجانبية، الناتجة عن ضغطِ الاحتراق على المكبسِ، أحد العواملِ التي تُؤثّرُ على التآكلِ في مبطّنِ الأسطوانة. الماكينة ثنائية عمود المرفق هي أحد الحلول للتغلب على التآكل في الأسطوانة. العمل الحاليُ يبحثُ في خصائصِ لتكلَ الأسطوانة في نموذجٍ لمحرك ثنائي عمود المرفق . كما جري اختبار تصميم لماكينتين أخريتين بتعديلِ النموذجِ. هاتين الماكينتين هما الماكينة التقليدية الحالية والماكينة التي يدور عمود المرفق بها حول نقطة مزاحة عن خط عمل المكبسِ. تُشير النَتائجَ إلى أن الماكينة ثنائية عمود المرفق هي تصميم واعد لتقليل الاحتكاك ومن ثم التآكل اللذين يشكلان دوراً مهماً في زيَادَة كفاءةٍ وعمر المحرّكِ.

ABSTRACT

Wear occurs in IC engines liners makes distortion in cylinder's liner. A distortion of the cylinders leads to deterioration of pressure inside cylinders and then losses in power i.e. less engine efficiency.

Side thrust force, caused by combustion pressure on piston, is one of the factors that affect wear in cylinder's liner. Twin crankshaft engine arrangement is one of many design concepts to overcome wear in cylinder. The present work investigates wear characteristics in cylinder using twin crankshaft engine model. Another two arrangements were tested by modification of the model. These two arrangements are inline (conventional) and offset crankshaft with respect to piston movement. Results show that twin crank shaft arrangement is a promising design to reduce friction and then wear, which both of them play important part in increasing engine efficiency and life time of engine.

Keywords: internal combustion engine, liner wear, offset crankshaft.

Nomenclature:

a	acceleration (m/s^2)
c	cylinder diameter (m).
F_r	rod applied force (N)
F_f	friction force (N)
F_t	side thrust force (N)
fmep	friction mean effective pressure or work to over come friction (atm).
mme	motoring mean effective pressure, or work required to motor an engine (atm).
m	piston mass (kg).
p	gas pressure (pa).

θ   the angle between the crank and the line joining the center of the crankshaft to the piston (deg).

φ   the angle between the connecting rod and the line joining the center of the crankshaft to the piston (deg).

1. Introduction:

Conventional internal combustion engines have been around for more than a century. Due to inherent high efficiency and low cost, IC engines continue to dominate many commercial markets, from passenger cars to

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ocean going vessels to on-site power generation. Because of its very high efficiency, the diesel engine is industry's leading prime mover, and will likely remain so for the foreseeable future.

The main idea for any internal combustion engine is the existence of a combustion chamber, in which fuel-air mixture exists. Then, this mixture is allowed to burn; either using a spark or by increasing its temperature and pressure of the mixture. Due to combustion, energy is liberated and the piston is forced to move and causes side thrust force against cylinder wall. This side thrust force is the normal friction force, which is the cause of wear in cylinder liner.

The material of such liners is not limited to that of the cylinder block type and can be optimized to give longer life and increased scuff resistance.

Piston rings, along with cylinder liners, present the major wear and maintenance problems existing in internal combustion engines. The wear in cylinder's liner cause distortion in the circular shape of the cylinder liner, Figure1.
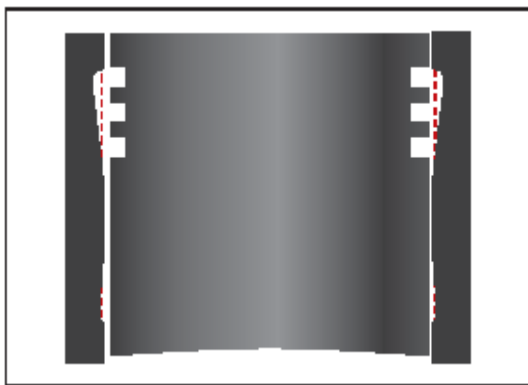

Figure 1: Cylinder liner distortion

Hence, the circular piston ring must conform to a slightly imperfect cylinder bore. Since the piston ring acts like an elastic beam, then the ring must successfully conform to a slightly distorted bore. However, if these distortions become too large, the ring may be unable to conform and loose its "light-tight" seal with the cylinder wall and piston. This seal breach may result in increased oil consumption and pressure leakage (blowby) and then lose of combustion pressure, which leads to power loss, which means deterioration of engine efficiency.

Chief result of the blowby is the traceable to excessive lubrication and resulting carbon formation around the rings, due to high temperatures encountered. Such formations hinder the free motion of the rings, and the lubricant seal is destroyed by leakage of gases under pressure past the rings. This action ultimately causes the rings to stick [3].

Piston ring misbehavior in an engine is indicated by loss of cylinder compression, poor oil control and noisy operation. These complaints are results of the cylinder liner wear.

Hot gases passing between the piston and the cylinder liner destroy the lubricant oil and lead to scoring, while the entire lubricating system of the engine is apt to be fouled with carbon and other combustion residues.

The aim of the present work is to investigate wear characteristics in cylinder liner using a twin crankshaft engine model, which is an attempt to reduce friction between piston and cylinder and then wear. Results show that twin crank shaft engine model is a promising solution to reduce wear when compared with in line (conventional) and offset arrangement using the same engine model with a little of modification.

2. Factors cause wear on engine's cylinder liners:

The main factor causing engines cylinder's liners wear are:

2. 1 Friction:

Friction occurs in all moving parts in the engine, like piston rings, journal bearings, valves and cams, but the piston and rings are responsible of about one half of the all engines friction.

Approximate measures for friction in internal engines can be realized by using motoring tests. The motoring mean effective pressure (mmep) is defined as the work per unit

displacement volume required to spin an engine operated without combustion [4].

Practical applications comes from the observation that under controlled conditions

$$fmep \approx mmep$$

A motoring test was carried out by Brown (1973) to measure the friction in internal combustion engines during disassembly of the engine parts, to study the distribution of friction among the various parts. Figure 2 shows:

A: Complete engine.

B: Complete engine minus intake and exhaust manifolds.

C: Setup B minus all valves, camshaft and measured pumping loss.

D: Setup C minus water pump.

E: Setup D minus oil pump.

F: Setup E minus all top and intermediate piston rings.

G: Setup F minus all piston rings.

H: Crankshaft only.

The first items removed were the manifolds and turbocharger curve (B). Next the valves and the camshafts, curve (C). As disassembly proceeds it becomes clear that pistons and
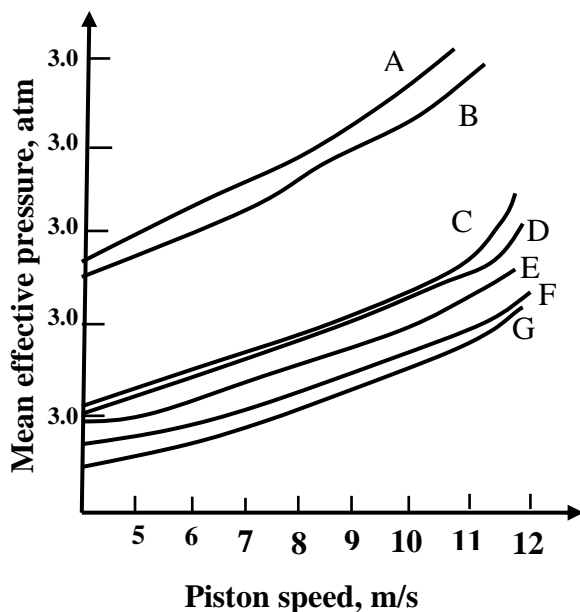
rings are responsible for about one half to three quarter of the friction.

Since friction due the piston and rings is the major component, it has received a lot of attention.

The friction due to the piston and its rings has been directly measured by an apparatus built by Liengood and Wallour (1947), the following features were noted [4]:

- Friction forces are comparable on the compression-intake and compression-exhaust strokes.

- Friction forces occurring during expansion are about twice as large as those occurring during any other stroke.

- Friction forces tend to be high just after top and bottom dead centers.

2.2 Engine speed:

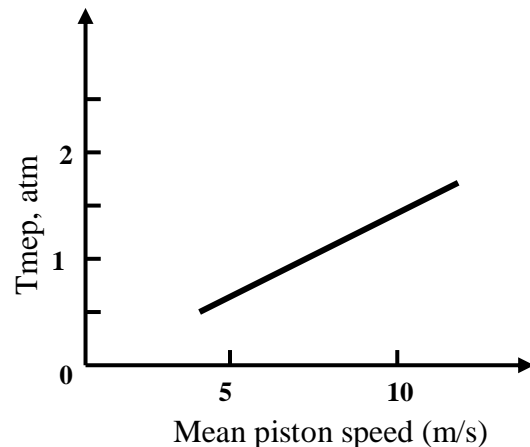Data obtained by Brown (1973), figure 3, shows that for any given engine, increasing piston speed increases the friction.

Figure 3: friction mean effective pressure

The figure above showed that friction depends mainly on piston speed.

2.2.3 Side thrust force:

One of the most important factors effecting on the cylinder liner is the inertia load or the side thrust force.

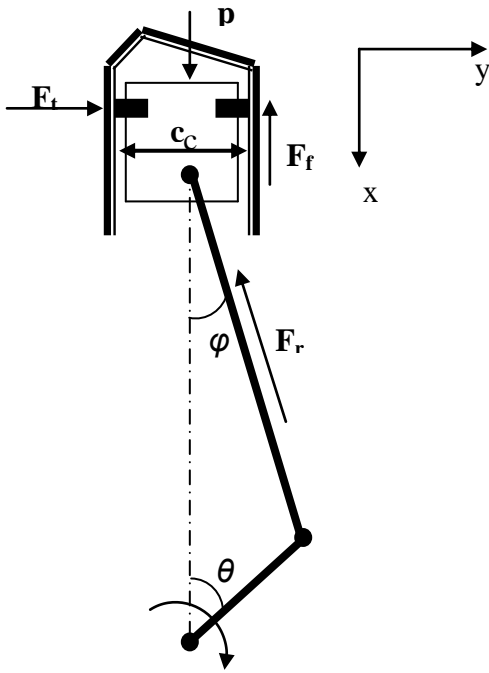Figure 4, illustrates a force balance applied to the piston:

Figure 2: Motored friction during disassembly of a diesel engine

Figure 4: Piston force balance

Side thrust force can be calculated from Newton's first law (F=ma) in the x direction:

$$F_x = ma = -F_r \cos\varphi + p\frac{\pi}{4}c^2 \pm F_f \qquad (1)$$

$$F_y = 0 = F_t - F_r \sin\varphi \qquad (2)$$

Therefore:

$$F_t = \left(-ma + p\frac{\pi}{4}c^2 \pm F_f\right)\tan\varphi \qquad (3)$$

The side thrust force switches sides as the piston passes through top and bottom center. Notice that near top dead center the friction force changes sign. Cylinder pressure during expansion is greater than during compression, which means that the side thrust on the left during expansion will be greater than that on the right during compression. In this case the left side is referred to as the major thrust side whereas the right side is called the minor side. Engines show more upper cylinder wear on the major thrust side than on the minor thrust side as a result [4].

There is another important factor affecting on the above phenomenon, the piston rings, which perform the critical role of sealing the gap between the piston and cylinder liner, are lubricated by very thin film oil. However, due to the very low magnitude of sliding speed around the top dead center position (TDC), piston rings do not "hydroplane" on the oil film as they do at mid stroke in the cylinder. Consequently, metallic contact at TDC creates wear, and can increase friction coefficient very significantly.

Equation (3), show that side thrust force is depends mainly on the mass of the piston, acceleration, gas pressure and angle φ.

Beside the wear in cylinder's liner, the side thrust force is responsible of the noise problem and the vibration occurs as a result of the unbalance forces [5].

3. Methods to reduce wear in cylinder's liner:

Engines manufactures continue to develop engines designs to overcome causes of wear in cylinder, which reduces the life time of the engines, and to optimize engine efficiency and reduce fuel consumption.

Twin crankshaft engine is one of design concepts, which is introduced as an attempt to reduce wear in cylinder liner. The aim of the present work is to investigate wear characteristics for the twin crankshaft arrangement

3.1 Twin crankshaft arrangement:

In conventional internal combustion engines, pistons are driven by a single crankshaft through a single connecting rods extending between a wrist pin centrally located in the piston and a crankshaft pin. This arrangement has problems with balance, noise and sidewall thrust on the piston resulting in undesirable friction [6].

Using one connecting rod in conventional internal combustion engines creates side thrust force, as shown in Figure 4. In twin crankshaft arrangement these opposite thrust forces canceled each other.

Side thrust force causes unbalance and noise problems in conventional engine; the additional crankshaft, in twin crankshaft engines, improves engines balance by eliminating piston side thrust force and its

associated friction, which cause wear in cylinder liner [7]. Figure 5, shows piston force diagram in twin crankshaft engine. It is clear, theoretically, that the side thrust forces have been eliminated.

The basic mechanism of the twin crankshaft engine, Figure 6, includes two, geared together, counter-rotating crankshafts which are transversely aligned along parallel axes of rotation and symmetrically spaced apart. Two connecting rods are similarly aligned and have the small ends on the same wrist pin, and the big ends are connected each to one of the two crankshafts.

The two connecting rods overlap during a portion of their motion, so one of the two connecting rods use a forked configuration, with a single big end connected to the crankshaft and a double small end connected to the wrist pin. The other connecting rod has a single flattened, blade-like configuration to pass between the two spaced second ends of the forked connecting rod.
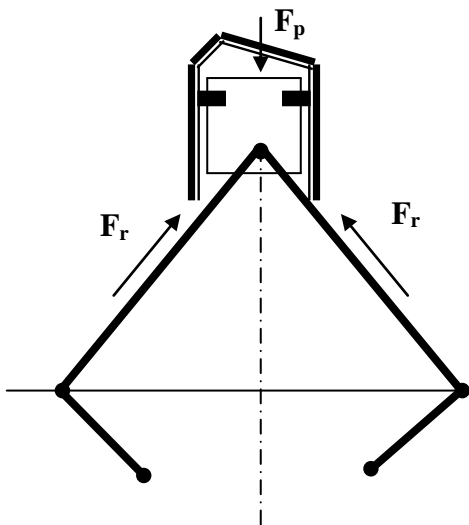
Figure 5: piston force balance

The duration of the piston strokes in the twin crankshaft engine are not equal, as a result of the offset of the crankshaft from the centerline of the piston motion. The expansion and the intakes strokes are longer than the compression and exhaust strokes; these characteristics have benefits just like improving cylinder filling with fuel-air charge and a longer more complete and cleaner burn.
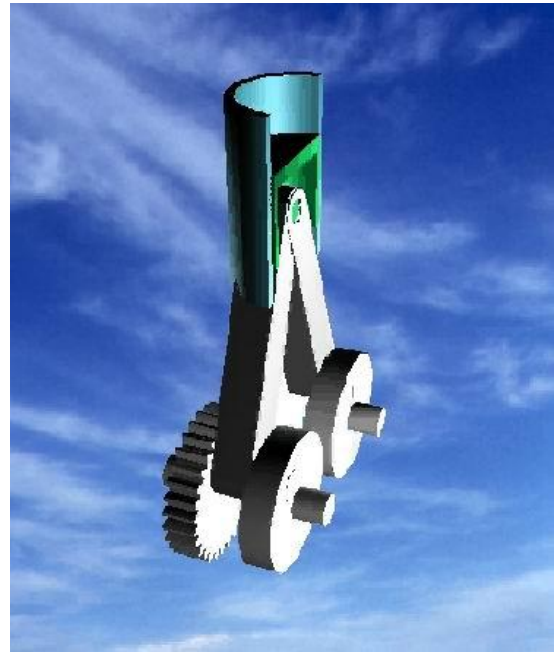

Figure 6:twin crankshaft engine

The second crankshaft introduced in this engine, can be used for various purposes like mounting rotating accessories, couplings, gears, pulleys, camshaft or any other components. While the first crankshaft can be used for driving a car, generator, pump or any other machine.

In conventional internal combustion engines the length of the stroke is equal to two times the length of the crankshaft:

$$s = 2\ r$$

While the stroke in a twin crankshaft engine with the same crankshaft length has a longer stroke. This change in length increases the effective displacement of the piston. As a result the compression ratio will also increase, and that will lead to increasing the engine efficiency.

Another advantage of using twin crankshaft engine is sharing the dynamic loads by the two crankshaft instead of one crankshaft in the conventional engines, that permits the support bearings to be smaller and increases the crankshaft life.

In similar manner, each connected rod now is taking half of the load, and that permit to use a little light connecting rod.

3.2 Offset crankshaft arrangement:

Offset crankshaft arrangement was established by simply removing one of the connecting rods leaving the model with one connecting rod with offset rotating position of the crankshaft. This is another approach to reduce horizontal component of the pushing force [8]. When the reduction of friction loss is deemed worthwhile, relatively simple design changes make it possible. This particular source of loss is most severe during the combustion stroke when the hot gasses push down on the piston. The connecting rod that links the piston to the crankshaft makes an angle with the axis of the piston so that as the piston pushes down , in the same time pushed to one side, hard against the cylinder wall. By simply moving the crankshaft a bit to one side, the connecting rod can be made more upright during the combustion stroke so that the force of the piston against the cylinder wall is smaller and hence friction is reduced [8]. Garvin; Edward **A.** **(**1998) used this technique to improve internal combustion engine efficiency.
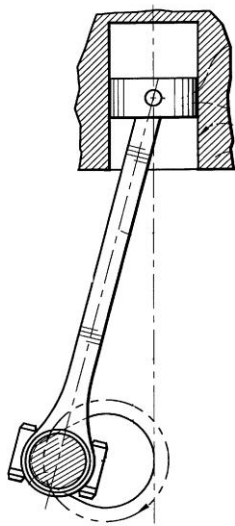
Figure 7: offset crankshaft

Figure 7, shows the offset crankshaft arrangement.

4. Experimental test rig:

Figure 6 shows a twin crankshaft engine's model, which is built at Sudan University of Science and Technology/ Collage of Engineering, to carry out tests to investigate wear characteristics in cylinder liner.

The model consist of two spur gears, two flanges, two connecting rods and connecting rod pins, a piston and piston rings and piston pin, a liner, casing, pulley, an electric motor to drive the model and a belt to transmit the power from the electric motor to the model.

Model parts designed using same equations and methods, which are used in conventional internal combustion engines parts design.

The same model used as an offset crankshaft engine by removing one of the connecting rods.

The inline configuration was established by moving the center of rotation of crankshaft from offset position to be inline with piston movement center line (conventional arrangement).

Three sets of tests were carried out to investigate wear characteristics in cylinders liner:

1. Inline crankshaft engine model
2. Offset crankshaft engine model
3. Twin crankshaft engine model

5. Tests Procedures:

1- Measure bore diameter of liner in four different angles at seven points of piston displacement, Figure 8, by using a dial bore gauge.
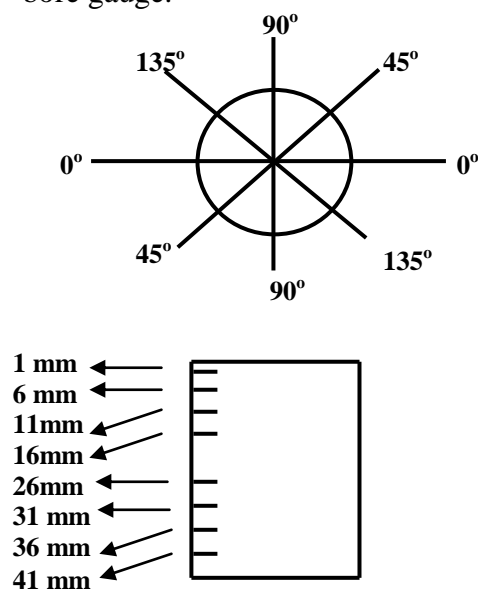

Figure 8: Measurement positions

2- Weight the liner and fit it in position.

3- Operate the electric motor at high speed for 150 minutes.

4- Repeat step 1 and 2 every 30 minutes.

5- Repeat steps 1 to 4 for the different crankshaft arrangements.

6- Repeat steps 1-5 using low motor speed.

Wear measurements were carried out by traversing liner bore vertically at different angles around bore diameter.

6. Results and Discussion:

6.1 Figures 9 and 10 show results of the first set of tests. These figures shows that wear occur in inline crankshaft engine is concentrated in one of the four measure angles (0 angle), and that is the result of the side thrust force.

6.2 Figures 11 and 12 show results of the second set of tests. These figures show a wear distribution in offset crankshaft engine, but with less amount of wear than the inline crankshaft engine. This can be explained by the reduction of side thrust force compared with the conventional engine.

6.3 Figures 13 and 14 show results of the first set of tests. These figures shows that wear occur in twin crankshaft engine is distributed over the whole liner, without any wear concentration in one of the four measure angles. Wear occurs in twin crankshaft engine is just due to the rings tight seal.

6.4 Figures 15 and 16 show comparison between the different model arrangements. From these figures, it is clear that wear occurs in twin crankshaft engine is less than the other engines arrangement.

In all figures, wear occurs when using high motor speed is greater than wear occurs when using a low motor speed.

6.5 figure 17 shows comparison between the three engines arrangement wear rate at the high and low speeds.

The figure shows high wear rate at the high speed, this is agree with work done by Brown (1973).

7. Conclusions:

1- Wear characteristics have been investigated for different crankshaft arrangements test rig.

2- Twin crankshaft arrangement is a good solution for wear reduction.
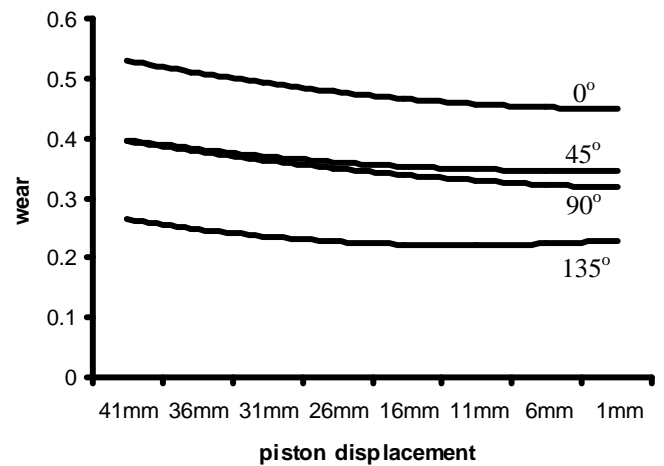
3- Increasing engine speed leads to increases wear.

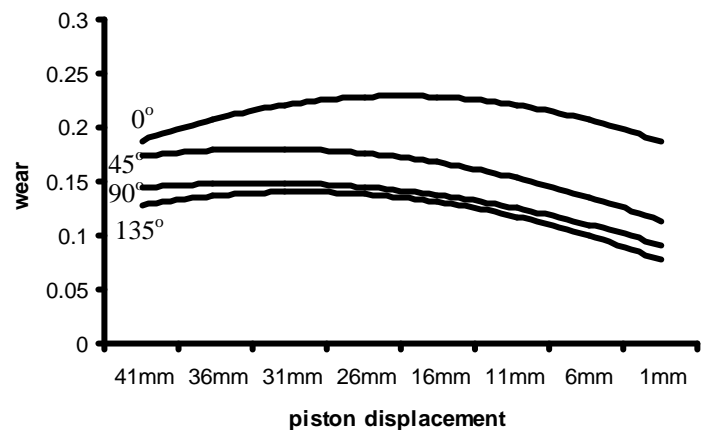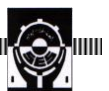**Figure 9: Wear occurs in inline crankshaft engine's liner- at high speed - after 150 minutes**

Figure 10: Wear occurs in inline crankshaft engine's liner- at low speed - after 150 minutes
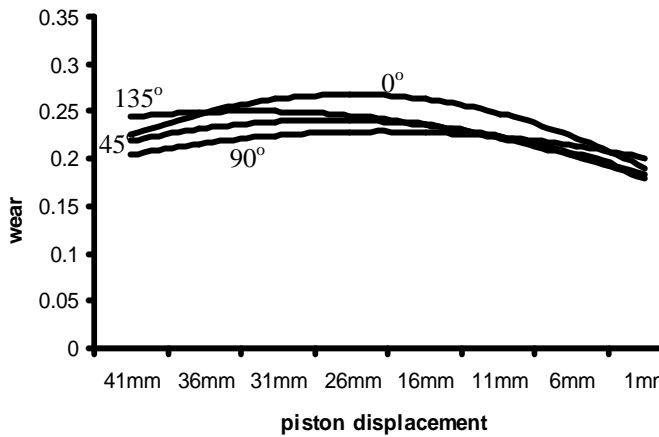
Figure 11: Wear occurs in offset crankshaft engine's liner- at high speed - after 150 minutes
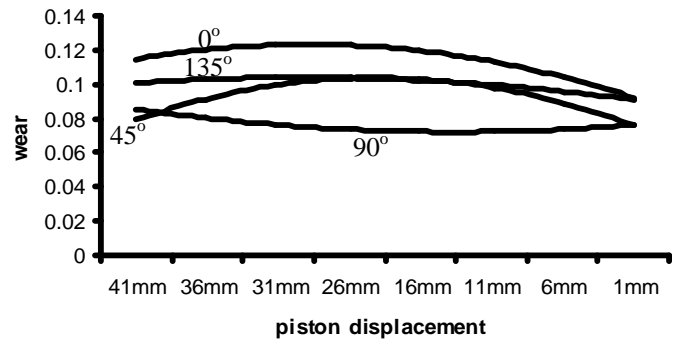

Figure 14: Wear occurs in twin crankshaft engine's liner- at low speed - after 150 minutes
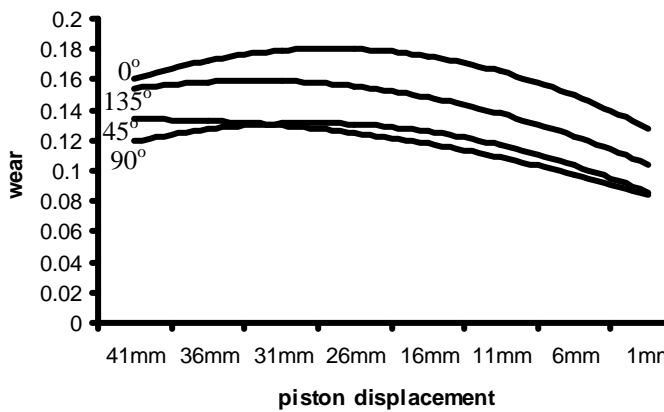

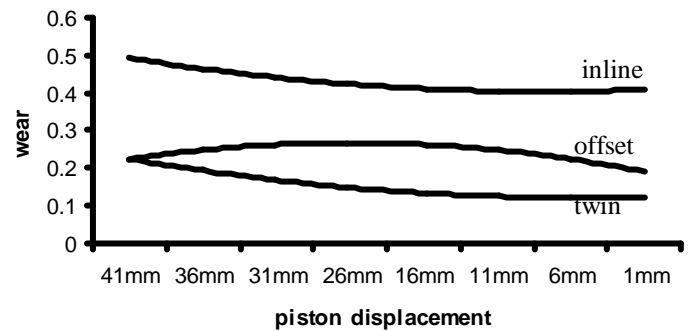**Figure 12: Wear occurs in offset crankshaft engine's liner- at low speed - after 150 minutes**

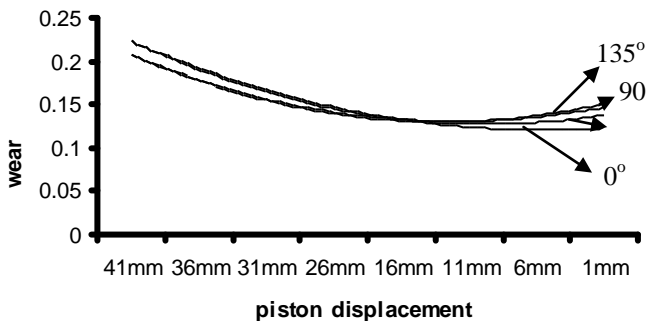**Figure 15: Liner wear comparison between inline, twin and offset crankshaft engine at 0 angle-high speed**

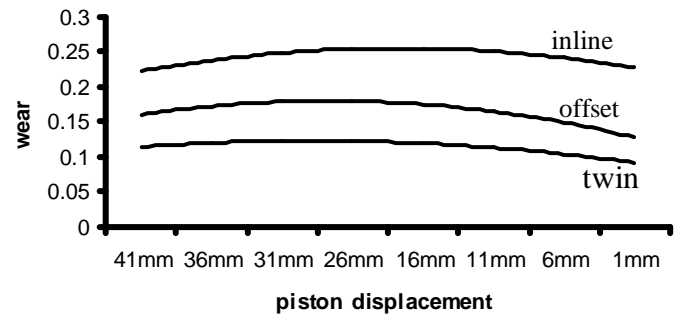**Figure 13: Wear occurs in twin crankshaft engine's liner- at high speed - after 150 minutes**

Figure 16: Liner wear comparison between inline, twin and offset crankshaft engine at 0 angle-low speed
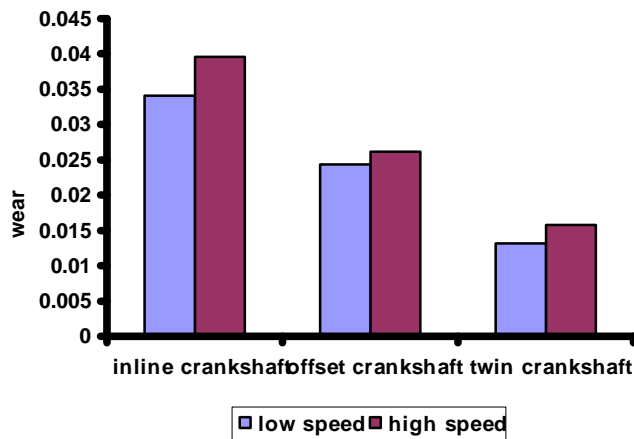
Figure 17: Wear rate

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