Theoretical performance comparison between inline, offset and twin crankshaft Internal combustion engine models

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Abstract:

Twin crankshaft is a new engine arrangement introduced to overcome cylinder's liner wear problems encountered in the conventional inline crankshaft engine due to the effect of the side thrust force. The offset crankshaft arrangement was also introduced to solve the same problem. In this work a computer programs was built to obtain the theoretical performance comparison between the three engines arrangements (inline, twin and offset crankshaft engines), and compared the theatrical performance with the experimental results, which done to the engine's models.

The study results show that the twin crankshaft engine model exhibited no thrust force, and that the thrust force in the offset crankshaft model is smaller than that in the inline crankshaft engine model. These agree with experimental results obtained from the same engine model.

Terminology:

a	the piston acceleration, (m/s2).
b	the length of the piston rod.
d	the offset of the axis of the crankshaft from the vertical path of the piston.
F	force acting at the end of the crank arm, (N).
$F_{(thrust)}$	side thrust force
g	acceleration of gravity
L	maximum displacement
m.	the mass of the piston, piston pin, piston ring and apart of the connecting rod, (kg)
m_1	the mass of the connecting rod which will be added to the mass of the piston.
m_2	the mass of the connecting rod which will be added to the mass of the crankshaft.
N	force acting on the piston,(N).
P	the power provided by the electric motor (kW),
r	the radius of the crankshaft (mm).

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T	the torque, (N.m).
s	Piston displacement (mm
α	the angle between the force F and the connecting rod, (deg).
θ	the angle of the radius vector relative to a vertical line through the axis of the crankshaft (deg).
φ	the angle between the connecting rod and the axis of the piston, (deg).
ω	angular velocity

1. Introduction

The main factor causing wear in the cylinder's liner is the side thrust force [1], which is created because the connecting rod makes an angle with the axis of the piston so that as the piston pushed down, it pushed it self to one side, hard against the cylinder wall. The side thrust force switches sides as the piston passes through top and bottom center.

When using twin crankshaft engine, fitted with two connecting rods, every connecting rod has it's own side thrust force and, as a result, they cancel each other [2,3].

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, and that is what happens when using an offset crankshaft [4].

Besides canceling the side thrust force, the twin crankshaft engine has many other advantages, just like reducing engine's vibrations and noise, and maintaining excellent engine's balance.

When using two crankshafts with two connecting rods attached to a single piston, that means the rotation point of the crankshafts must be offset from the axis of the piston movement.

This offset makes differences in piston displacement, speed and acceleration from the conventional engines. Also the intake and power strokes are not equal to pressure and exhaust strokes [5], and the angle between the connecting rod and the axis of the piston (φ) is grater than the conventional ones.

The length of crank arm (r), connecting rod (b) and the offset of the crank from the ordinary point (d), controls the offset and twin crankshafts engines specifications.

To make a comparison between the inline (conventional) engine and the offset crankshaft engine and the twin crank shaft engine a FORTRAN program used to calculate the three engines performance. The program first calculate the displacement, speed and acceleration of the offset crankshaft engine with different values of (r), (b) and (d). Then the program used to calculate the side

thrust force, acceleration and the force (N) applying on the piston for the three engines (inline, offset and twin crankshaft) supposing that an electric motor drives the engines.
The initial conditions for the program was similarly to a model of a twin crankshaft engine built in Sudan University of science and technology/ Faculty of Engineering. The same mode after taking off one of its crankshafts was converted to an offset crankshaft engine model, and by transferring the point of the crankshaft rotation to the axis of the piston movement the model becomes an inline (conventional) crankshaft engine model. The model of the three engines arrangement was driven by an electric motor.

2. The computer program

As mentioned above the crank offset changes the values of piston displacement, speed and acceleration. The first part of the computer program deals with this issue. The second part deals with the inline crankshaft engine model performance, the third part with the offset crankshaft engine model and the last part deals with the twin crankshaft engine model.

2.1 First part: piston displacement, speed and acceleration with offset crankshaft

To derive the new equations we represent the rotation of the crank as a circle where the center of the circle would be the axis of the crankshaft and the circumference represents the rotation of the center of the journal. The piston's connecting rod is then represented as a straight line. Since the piston and the top of the piston rod travel the same vertical velocity, the piston itself is not a factor. Since this article is about the offset crankshaft, notice that the center of the circle representing the rotation of the journal is offset from the vertical line, which denotes the center of the piston [6]. Figure 1 shows this representation.
From figure 1:

$Y = Y_1 + Y_2$ (1)

$Y_2 = r*\cos\theta$ (2)

$X_1 = r*\sin\theta$ (3)

$Y_1^2 = b^2 - (X_1 + X_2)^2$ (4)

$X_2 = d$ (5)

From (1): $Y = Y_1 + Y_2$

From (2): $Y = r*\cos\theta + Y_1$

From (4): $Y = r*\cos\theta + \sqrt{\{b^2 - (X_1 + X_2)^2\}}$

From (3): $Y = r*\cos\theta + \sqrt{\{b^2 - (r*\sin\theta + X_2)^2\}}$

$S(\theta) = l - [r*\cos\theta + \sqrt{\{b^2 - (r*\sin\theta + d)^2\}}]$

But: $\theta = \omega t$

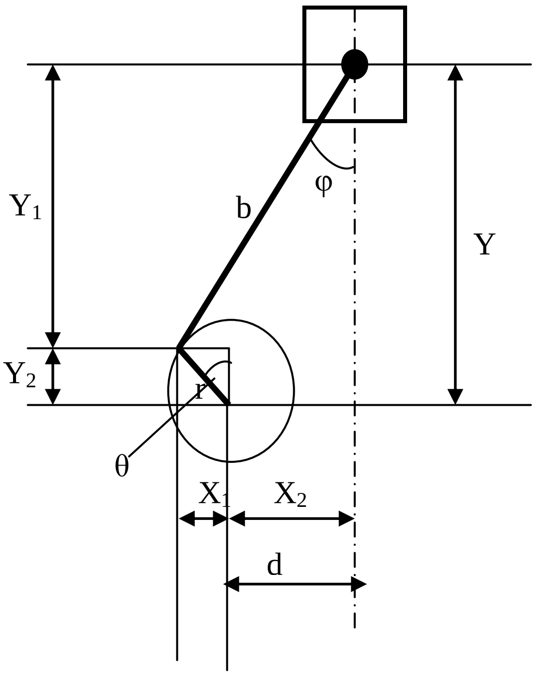


Figure 1:engine with offset crankshaft

Then:

S(ωt) =l- [r*cos (ωt) +√ {b^2-(r*sin (ωt) +d)^2}]

Taking the first and second derivative of the displacement to obtain the equations for velocity and acceleration respectively.

$$s(\omega t) = l - \left[r\cos\omega t + \sqrt{b^2 - (r\sin\omega t + d)^2} \right] \tag{6}$$

$$v(\omega t) = r\omega \sin\omega t + \frac{2\omega(r\sin\omega t + d)r\cos\omega t}{\sqrt{b^2 - (r\sin\omega t + d)^2}} \tag{7}$$

$$a(\omega t) = r\omega^2\cos\omega t + \frac{(r\sin\omega t + d)^2 r^2\omega^2\cos^2\omega t}{\left[\sqrt{b^2 - (r\sin\omega t + d)^2}\right]^3} - \frac{(r\sin\omega t + d)r\omega^2\sin\omega t + r^2\omega^2\cos^2\omega t}{\sqrt{b^2 - (r\sin\omega t + d)^2}} \tag{8}$$

Equations (6), (7) and (8) gives the values of displacement, speed and acceleration with offset crankshaft. These equations used to built a FORTRAN program, which calculate the following values with different values of (r) , (b) and (d):

1.Piston displacement. 2.Piston speed. 3.Piston acceleration. 4.The maximum value of angle (φ). 5. The (intake-power) stroke. 6.The (exhaust-pressure) stroke.

To calculate the value of the angle (φ), from Figure 1:

$$\varphi = tan^{-1}[(d + r \sin(\theta))/b]$$

To calculate the strokes in degrees of the crank angle, we find the angle of the crank at maximum piston displacement (i.e. top dead center TDC), and the angle at minimum displacement (i.e. bottom dead center BDC).

Figure 2 shows the program flow chart.

2.1.1 FORTRAN program for calculating piston displacement, speed, acceleration and the angle φ, with an offset crankshaft engine:

```
program acceleration
integer i
i = 0
omega = 261
r = 0.02
do while (r < 0.03)
d = 0
do while (d < 0.03)
b = 0.08
do while (b < 0.1)
do 1 I = 0,361
theta=i*3.142857143/180.0
s=r*cos(theta)+sqrt((b**2)-(r*sin(theta)+d)**2)
v=r*w*sin(theta)+(2*(r*sin(theta)+d)*r*w**cos(theta))
&/sqrt((b**2)-(r*sin(theta)+d)**2)
a=-r*cos(theta)*(w**2)
a1=(((r*sin(theta)+d)**2)*(r**2)*((cos(theta))**2)*(w**2))
a2=(sqrt((b**2)-(r*sin(theta)+d)**2))**3
a3=(r*sin(theta)+d)*r*sin(x)*(w**2)-(w**2)*(r**2)*(cos(theta))**2
a4=sqrt((b**2)-(r*sin(theta)+d)**2)
a5=a-(a1/a2)+(a3/a4)
phi=asin((d+r*sin(x))/b)
write i,s,a5, v,phi
```

```
1    continue
b = b+0.01
end do
d = d+0.01
end do
r = r +0.005
end do
end
```

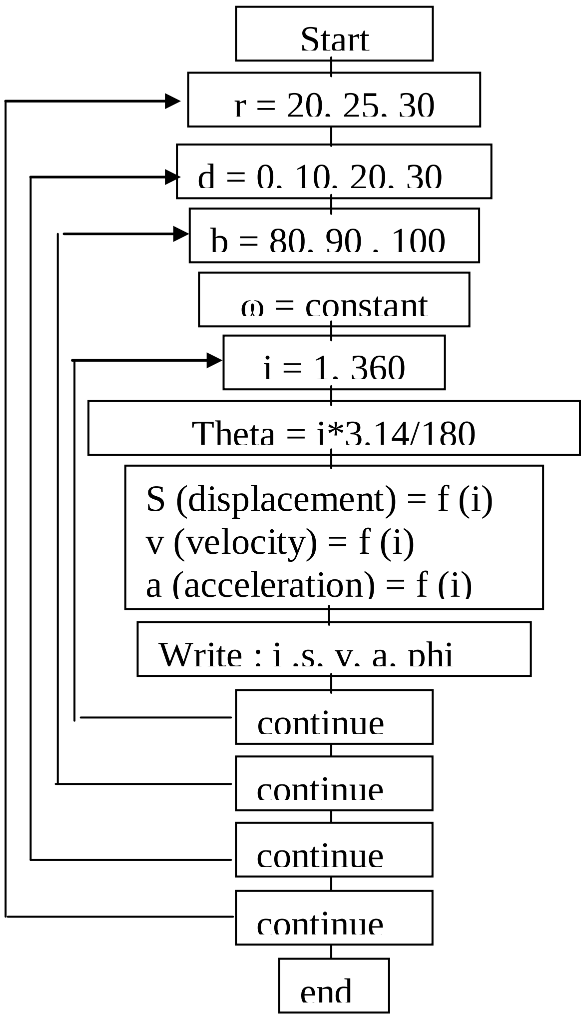


Figure 2:program flow chart

the result after running this program are shown in Table 3.

2.2 part two: inline crankshaft engine performance

the main equations used to calculate the force applying on the piston, acceleration and the side thrust force could be calculated as following:

Forces balance:

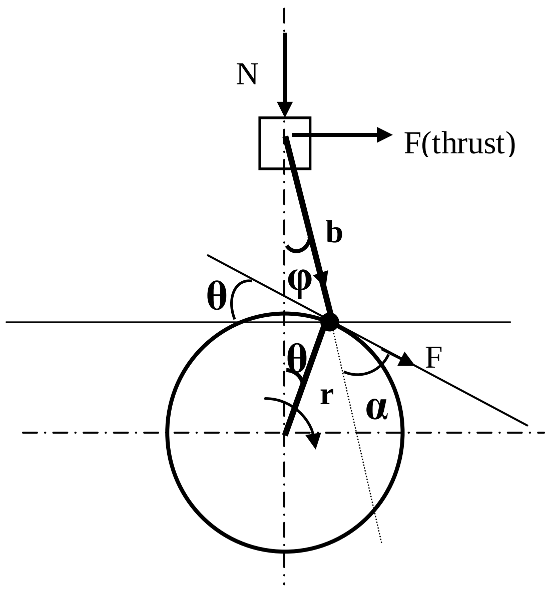


Figure 3: inline crankshaft engine

From figure 3:

$N = [F*\cos(\alpha)/\cos(\varphi)] - m*a \pm m*g$

$F = P/T = P/r*\omega = P/(2\pi n/60)*r$ (N)

$\sin(\varphi) = r*\sin(\theta)/b \Rightarrow \varphi = \sin^{-1}(r*\sin(\theta)/b)$

$\theta + \varphi + \alpha = 90^o$

$\Rightarrow \alpha = 90^o - [\theta + \sin^{-1}(r*\sin(\theta)/b)]$

m = piston + part of the connecting rod (kg)

$a = r*\omega^2*[\cos(\theta)+\cos(2*\theta)/(2*b/r)]$

$N = [F*\cos\{90^o - [\theta + \sin^{-1}(r*\sin(\theta)/b)]\}*\cos\{\sin^{-1}(r*\sin(\theta)/b)\}] - m*a \pm m*g$

(9)

$F_{(thrust)} = F*\cos(\alpha)*\sin(\varphi)$

$= F*\cos\{90^o - [\theta + \sin^{-1}(r*\sin(\theta)/b)]\}*r*\sin(\theta)/b$ (10)

The computation requires the masses of the piston and the connecting rod to calculate the moment of inertia. Theoretically the mass of the connecting rod could be divided to two separate masses, one of them added to the piston and it takes the piston acceleration, while the other added to the crankshaft and it takes the crankshaft acceleration.

2.2.1 Replacing the mass of the connecting rod by two separated masses

For calculating the moment of inertia for the piston, we must add a part of the connecting rod to the piston, according to the following rules [7]:

1- $m_1+m_2 = m$
2- $m_1 .\ a = m_2 .\ b$

Where:

m = 612.53 g from table 1.

From equation [1],[2]:

$$m_1 = \frac{b}{a+b} m \longrightarrow \quad [a]$$

$$m_2 = \frac{a}{a+b} m \longrightarrow \quad [b]$$

From equation [a] and figure 4:

$m_1 = 0.0612*0.61253/0.160 = 0.2343$ kg

From equation[a]:

$m_2 = 0.0988*0.61253/0.160 = 0.3782$ kg

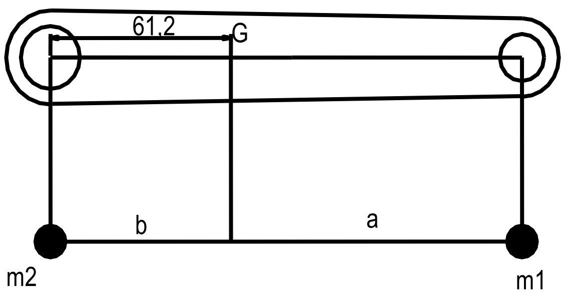


Figure 4:center of gravity for connecting rod 1

Remember that the model was for a twin crankshaft engine, that means it has two connecting rods, but when we use the model as an inline crankshaft engine, we toke off one of two crankshafts with its connecting rod. So by using the same method for the other connecting rod, and figure 5:

m_1 = 0.061253*0.61045/0.16 = 0.2451 kg
m_2 = 0.09597*0.61045/0.16 = 0.3674 kg

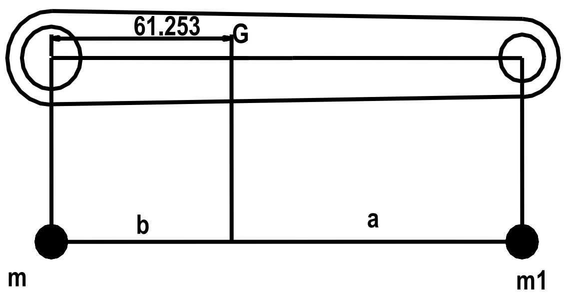


Figure 5:center of gravity for connecting rod 2

Table 1: model components weight

Item	Weight (kg)
Piston &piston rings	0.20681
Connecting rod 1	0.61253
Connecting rod 2	0.61045

By using equations (9) and (10) a FORTRAN program built to calculate the force applying on the piston and the side thrust force. Figure 6 shows the program flow chart.

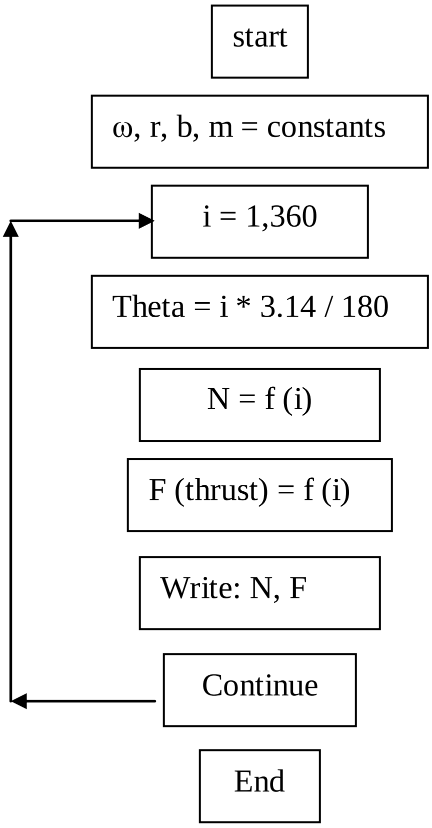


Figure 6: program flow chart for the inline crankshaft engine

2.2.2 FORTRAN program used to get the inline engine performance:

```
program inlinecrankshaft engine
integer i
omega =constant
r = 0.023
b = 0.092
m = 0.441
pi =3.141592654
do 10 I = 0,360
theta = i*pi/180
```

```
      F=196.6*cos((pi/2)-
      (theta+asin((r*sin(theta))/b)))*cos(asin((r*sin(theta))/b))
      a=r*(w**2)*(cos(theta)+(cos(2*theta))/(2*(b/r)))
      if(i.le.180)  N=F-a*m+m*9.81
      if(i.gt.180)  N=F-a*m-m*9.81
      Fthrust =196.6*cos((pi/2)-
      (theta+asin((r*sin(theta))/b)))*((r*sin(theta))/b)

      Write N, Fthrust, a
10    continue
      end
```

the results obtained after running the program are shown in table 4.

2.3 part three: offset crankshaft engine performance

The offset crankshaft is an engine introduced to reduce the effect of the side thrust force, which responsible of wear occurs on the liner, and the vibrations and noise problems.

Force balance:

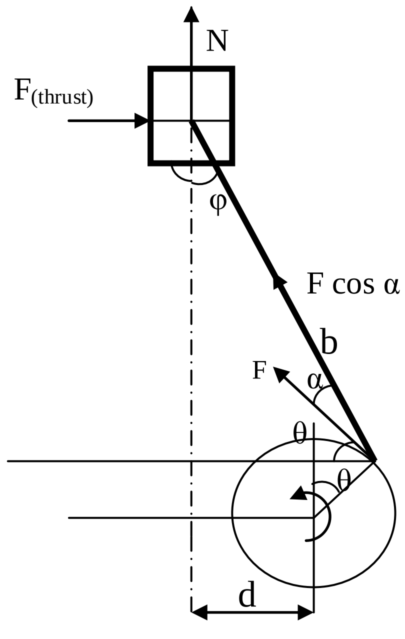


Figure 7:offset crankshaft engine

Figure 7 shows the force balance for the offset crankshaft engine. From figure 7:

$N = [F*\cos\alpha*\cos\varphi]-m*a \pm mg.$

Force (F) calculations:

$P = T*\omega = F*r*\omega \Rightarrow F = P/ r*\omega$

$\omega = 2\pi n/60$

$\varphi = \sin^{-1}[(d + r\sin\theta)/b]$

And: $\varphi + \theta + \alpha = 90^o$. Then: $\alpha = 90-(\varphi + \theta) = 90- (\sin^{-1}[(d + r\sin\theta)/b]+ \theta)$

Substituting these values in equation [c], then:

$$N = [F*\cos\{90- (\sin^{-1}[(d + r\sin\theta)/b]+\theta)\}*\cos\{\sin^{-1}[(d + r\sin\theta)/b]\}] - m*a \pm mg \longrightarrow \quad (11)$$

$$F_{(thrust)} = [F*\cos\{90- (\sin^{-1}[(d + r\sin\theta)/b]+ \theta)\}* [(d + r\sin\theta)/b]\}] \quad (12)$$

To calculate the force applying on the piston, the acceleration and the side thrust force, equations (11) and (12) used in a FORTRAN program with program flow chart similar to one shown in Figure 6.

2.3.1 FORTRAN program to calculate the offset crankshaft engine performance

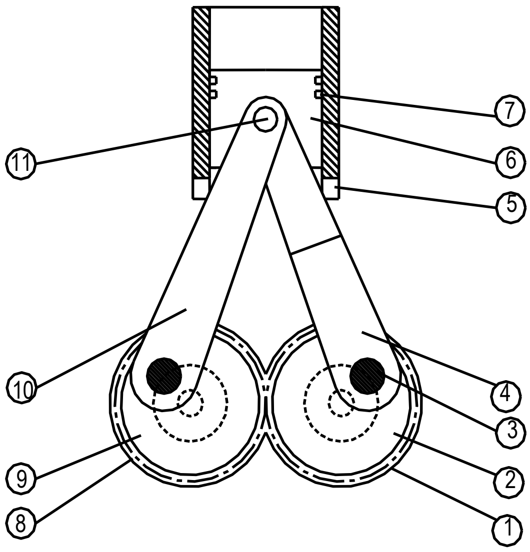
```
program offsetcrankshaft
integer i
i = 0
omega = 55
r = 0.023
b = 0.16
d = 0.045
do 1 i = 0,361
theta = i*3.142857143/180.0
a = -r*cos(theta)*(w**2)
a1=(((r*sin(theta)+d)**2)*(r**2)*((cos(theta))**2)*(w**2))
a2=(sqrt((b**2)-(r*sin(theta)+d)**2))**3
a3=(r*sin(theta)+d)*r*sin(theta)*(w**2)-w**2)*(r**2)*(cos(theta))**2
a4=sqrt((b**2)-(r*sin(theta)+d)**2)
a5=a-(a1/a2)+(a3/a4)
F=2*(98.289*cos(90-asin((d+r*sin(theta))/b)+theta))
F2=cos(asin((d+r*sin(theta))/b))
phi=asin((d+r*sin(theta))/b)
F1= m *a5
N=F*F2-F1
```

```
Fthrust= F*((d+r*sin(x))/b)
if (i.ge.185) N = F3+7.135
if (i.lt.185) F3 = F3-7.135
write(3,8) N, Fthrust
1        continue
         end
```

The results obtained after running the program are shown in table 5.

2.4 Part four: twin crankshaft engine performance

The twin crankshaft engine is consisting of two crankshafts, tow flanges, two connecting rods, a piston and liner. Figure 8 shows the twin crankshaft model components.



1	1st gear	7	Piston's rings
2	1 st flange	8	2nd gear
3	Crank pin	9	2nd flange
4	1st connecting rod	10	2nd connecting rod
5	Liner	11	Piston wrist pin

Figure 8: twin crankshaft engine components

Using Figure 9, which shows the force balance in the twin crankshaft engine, the theoretical values for the force applying on the piston and the side thrust force were calculated.

From Figure 9:

$N = [F*\cos\alpha*\cos\varphi]-m*a \pm mg.$

Force (F) calculations:

$P = T*\omega = F*r*\omega \Rightarrow F = P/r*\omega$

$\omega = 2\pi n/60$

$N = [F*\cos\alpha*\cos\varphi]- 0.\ 0.68621*a \pm 0.72733*9.81.$ (c)

But from figure 5:

$\varphi = \sin^{-1}[(d + r\sin\theta)/b]$

And:

$\varphi + \theta + \alpha = 90^{o}$. Then: $\alpha = 90-(\varphi + \theta) = 90- (\sin^{-1}[(d + r\sin\theta)/b]+ \theta)$

Substituting these values in equation (c), then:

$\Rightarrow N = 2*[F*\cos\{90- (\sin^{-1}[(d + r\sin\theta)/b]+ \theta)\}*\cos\{\sin^{-1}[(d + r\sin\theta)/b]\}] - m*a \pm mg$ (13)

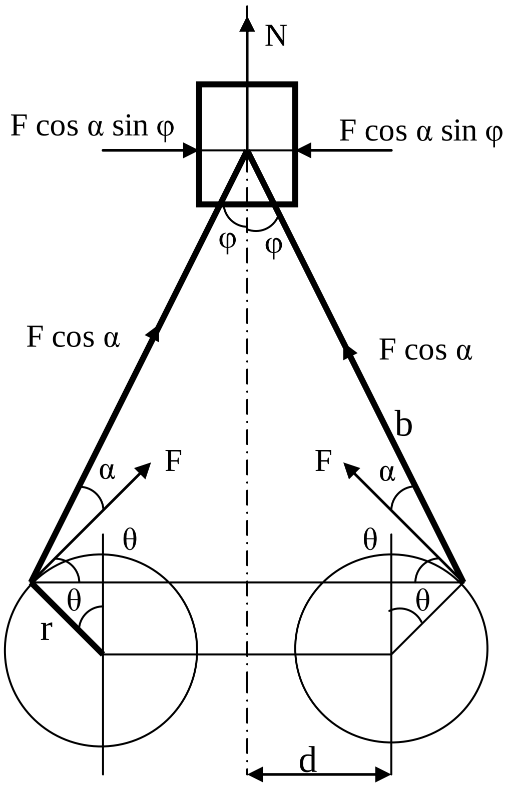


Figure 9: twin crankshaft engine piston's forces balance

as shown from Figure 9, there is no side thrust force in the twin crank shaft engine, that means:

F thrust = 0 ⟶ (14)

A Fortran program was written to calculate the acceleration, and the force applying on the piston, for a crank angle from 0^o to 360^o. The program flow chart is similar to that shown in Figure 6.

2.4.1 FORTRAN program to calculate the twin crankshaft engine performance

```
      program twincrankshaft
      integer i
      i = 0
      omega = 55
      r = 0.023
      b = 0.16
      d = 0.045
      do 1 i = 0,361
      theta = i*3.142857143/180.0
      a = -r*cos(theta)*(w**2)
      a1=(((r*sin(theta)+d)**2)*(r**2)*((cos(theta))**2)*(w**2))
      a2=(sqrt((b**2)-(r*sin(theta)+d)**2))**3
      a3=(r*sin(theta)+d)*r*sin(theta)*(w**2)-
      (w**2)*(r**2)*(cos(theta))**2
      a4=sqrt((b**2)-(r*sin(theta)+d)**2)
      a5=a-(a1/a2)+(a3/a4)
      F=2*(98.289*cos(90-asin((d+r*sin(theta))/b)+x))
      F2=cos(asin((d+r*sin(theta))/b))
      phi=asin((d+r*sin(theta))/b)
      F1=0.68621 *a5
      N= F*F2-F1
      if (i.ge.185) N=N+7.135
      if (i.lt.185) N=N-7.135
      write(3,8) N
1     continue
      end
```

3. Results and discussions:

Using equations (6,7,8,9,10,11,12,13,14), a Fortran program was written to calculate the acceleration, side thrust force and the force applying on the piston, and the displacement, speed and strokes of the engines, for a crank angle from 0^o to 360^o.

Tables 2,3,4,5 and figures 10,11,12 and 13 show the results.

Table 2: Inline crankshaft engine acceleration, force applying on the piston and the side thrust force:

Crank angle (deg)	Acceleration (m/s^2)	Force(N)	Side thrust force (N)
0	69.64687	26.39399	0.00E+00
20	65.43082	-51.63659	3.750969
40	53.29742	-119.9942	12.91964
60	34.72611	-168.787	22.56177
80	11.9755	-193.5434	27.81737
100	-12.1972	-194.5941	26.43666
120	-34.8741	-175.0811	19.48433
140	-53.3289	-139.1347	10.31472
160	-65.3507	-90.97118	2.837276
180	-69.5031	-3.48E+01	3.87E-05
200	-65.2907	33.75497	2.877342
220	-53.2161	92.49712	10.37952
240	-34.722	144.6551	19.54749
260	-12.024	184.0577	26.46976
280	12.14887	204.1696	27.80252
300	34.87872	199.2878	22.50297
320	53.41074	166.6793	12.84483
340	65.49104	108.8672	3.699465

Table 3: the displacement, maximum piston speed, acceleration, angle (φ) and the intake and pressure strokes with different values of crank arm (r), offset (d), and the length of the connecting rod (b):

r (mm)	d (mm)	b (mm)	Displacement (m)	Maximum Speed, (m/s)	Maximum Acceleration (m/s^2)	Maximum φ (Degrees)	Intake stroke (Degrees)	Pressure stroke (Degrees)
20	0	80	.040000	5.230601	1021.815	14.48485	180	180
		90	.040000	5.229271	1059.66	12.84610	180	180
		100	.040000	5.228226	1089.936	11.54281	180	180
	10	80	.040338	5.237028	1078.475	22.03548	184	176
		90	.040262	5.234789	1090.590	19.48109	183	177
		100	.040210	5.233074	1108.642	17.46645	182	178
	20	80	.041410	5.244868	1194.918	30.01521	188	172
		90	.041084	5.241053	1167.907	26.40110	186	174
		100	.040861	5.238430	1161.325	23.59013	185	175
	30	80	.043432	5.657467	1387.399	31.51738	192	168
		90	.042584	5.249264	1294.357	33.76610	189	171
		100	.042027	5.244871	1249.223	30.01521	187	173
25	0	80	.050000	6.542137	1198.103	18.21919	180	180
		90	.050000	6.539951	1232.466	16.13580	180	180
		100	.050000	6.538251	1277.269	14.48485	180	180
	10	80	.050438	6.550787	1333.175	25.95764	185	175
		90	.050338	6.547251	1319.939	22.89698	184	176
		100	.050268	6.544589	1327.311	20.49770	183	177
	20	80	.051842	6.562311	1538.667	34.24622	190	170
		90	.051401	6.556084	1461.077	30.01521	188	172
		100	.051104	6.551742	1426.492	26.75724	187	173
	30	80	.054525	7.366423	1871.620	43.45456	196	164
		90	.053354	6.679641	1675.406	37.68898	193	167
		100	.052608	6.560997	1575.341	33.38393	190	170
30	0	80	.060000	7.855540	1423.229	22.03548	180	180
		90	.060000	7.852183	1425.471	19.48109	180	180
		100	.060000	7.849609	1449.296	17.46645	180	180
	10	80	.060553	7.867294	1644.735	30.01521	187	173
		90	.060421	7.861577	1584.384	26.40118	185	175
		100	.060331	7.857644	1562.566	23.59013	183	177
	20	80	.062339	7.883499	1971.952	38.70180	193	167
		90	.061752	7.873888	1809.129	33.76610	190	170
		100	.061370	7.867299	1724.858	30.01521	188	172
	30	80	.065830	9.215178	2526.240	48.61502	201	159
		90	.064227	8.323761	2147.836	41.83151	195	165
		100	.063243	7.879830	1956.695	36.88859	192	168

Table 4: Offset crankshaft engine acceleration, force applying on the piston and the side thrust force:

Crank angle (deg)	Acceleration (N)	Force (N)	Side thrust force (N)
0	80.89231	6.326322	-9.87E00
20	67.54444	-51.07028	-29.8254
40	42.6129	-105.1166	-51.6636
60	11.27526	-150.3619	-70.8842
80	-19.5274	-180.5339	-82.2356
100	-43.6843	-189.4166	-81.4010
120	-58.2845	-172.5222	-67.0826
140	-63.9644	-129.1493	-42.388
160	-63.1957	-64.02534	-14.1626
180	-58.2338	1.26E+01	9.94E+00
200	-50.0658	78.55049	25.02212
220	-38.4392	138.4455	30.68857
240	-22.5405	175.4288	30.08532
260	-1.98668	187.2101	27.13418
280	22.19965	176.2005	24.09378
300	47.09035	147.0719	20.7539
320	68.20893	104.7379	15.20888
340	80.69968	53.5164	5.315868

Table 5: twin crankshaft engine acceleration, force applying on the piston:

Crank angle (deg)	Acceleration (N)	Force (N)
0	80.89231	28.55853
20	67.54444	-32.1098
40	42.6129	-92.2671
60	11.27526	-145.194
80	-19.5274	-182.916
100	-43.6843	-197.719
120	-58.2845	-184.404
140	-63.9644	-142.423
160	-63.1957	-77.1106
180	-58.2338	7.25E-01

200	-50.0658	63.87416
220	-38.4392	126.619
240	-22.5405	167.4992
260	-1.98668	184.3185
280	22.19965	179.2372
300	47.09035	156.2095
320	68.20893	119.0519
340	80.69968	70.892
360	80.84415	14.66689

3.1 Table 3 shows the variation of piston displacement, speed, acceleration, angle (φ) and the (intake-power), (exhaust-pressure) strokes, with three values for the crank arm (r), for values for the offset value (d), and four values for the length of the connecting rod (b). When d = 0 the engine returns to a conventional one, with four equal strokes, and the piston displacement equals 2r. But when an offset happens, the strokes becomes unequal, the intake-power strokes are greater than the two other strokes.
This phenomena gives a grate advantage to the offset and twin crankshaft engines, because when the intake stroke becomes greater than 180^o, that gives the air an addition time to fill the cylinder, and that improves the volumetric efficiency.
Also when the power stroke becomes greater than 180^o,that maintained a complete, clean burn, which improves the engine's efficiency [2, 3].
3.2 Figure 10 shows the theoretical acceleration comparison between the twin crankshaft engine, the inline crankshaft engine and the offset crankshaft engine. It shows that there is no a sensitive difference in the acceleration value between the three engines arrangements, but the maximum and minimum values of the acceleration in the case of twin and offset engines are located in different crank angle compared with the inline crankshaft engine. The offset is the chief cause of this behavior.
3.3 Figure 11 shows the theoretical side thrust force comparison between the inline crankshaft engine, the offset crankshaft and the twin crankshaft engines. The side thrust force equals zero for the twin crankshaft engine, and it switching sign after the first 180^o in the offset crankshaft case.
The use of electric motor instead of combustion to drive the model causes the side thrust force in case of inline crankshaft engine model to be always in the same side without switching from side to side as expected for the inline crankshaft engine.

These results are agreed with the experimental tests done on the same model. Figure 13 shows a liner wear comparison between the inline, offset and the twin crankshaft engines. The figure shows much wear in the inline crankshaft engine, and less wear in the twin crankshaft engine, because the absence of the side thrust force in the twin crankshaft engine [8].

3.4 Figure 12 shows the theoretical force (applying on the piston) comparison between the twin crankshaft engine, the inline crankshaft engine and the offset crankshaft engine.

The figure shows a similarity between the forces in the three types of engines.

7. Conclusion:

1. The twin crankshafts decrease the liner wear by canceling the thrust force.
2. The twin crankshaft increases the life of the crankshaft group by distributing the load between the two shafts components.
3. The twin crankshafts offer a good possibility of fixing weight balances.
4. The twin crankshafts eliminate engine vibrations produced by the reactive moment.
5. The twin crankshafts increases engine width and entail the use of more moving parts of the engine. This point should economically be considered.

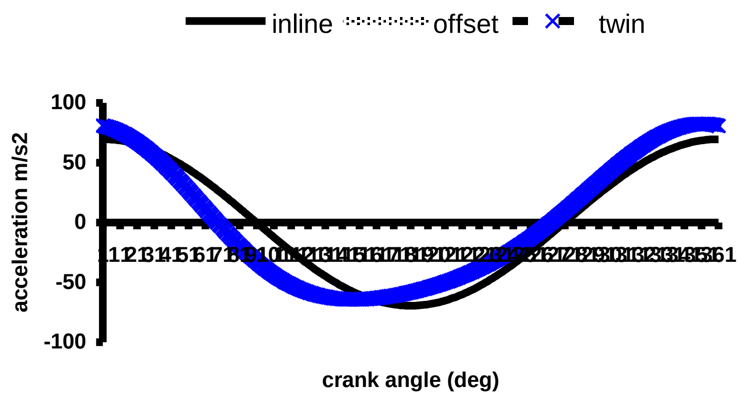


Figure 10: Piston acceleration comparison between inline, offset and twin crankshaft engines

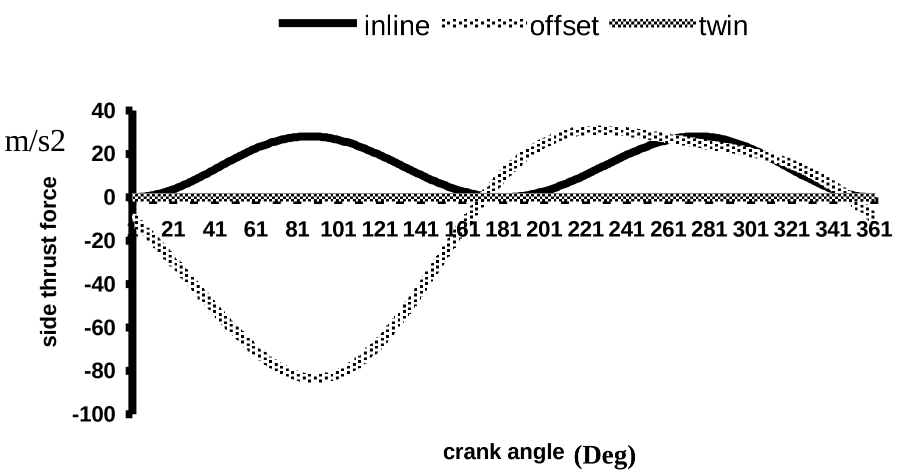
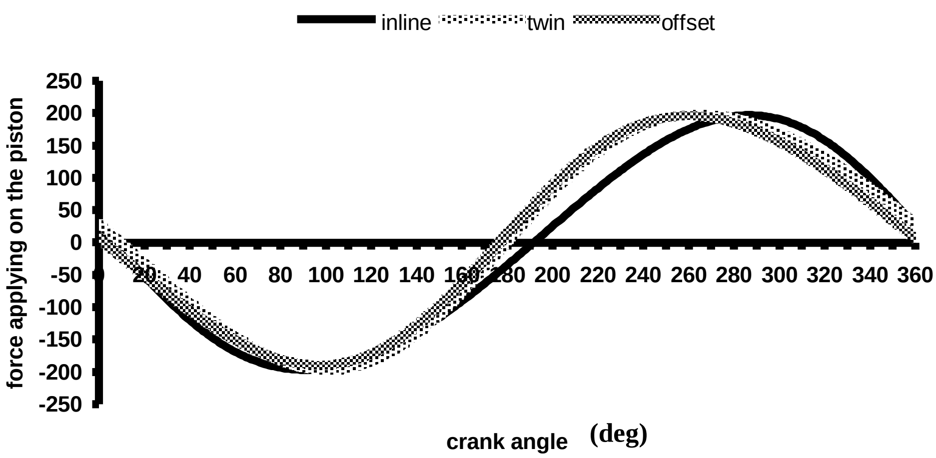


Figure 11: Side thrust force comparison between inline,



offset and twin crankshaft engines

Figure 12: Piston force comparison between inline, Offset and twin crankshaft engines

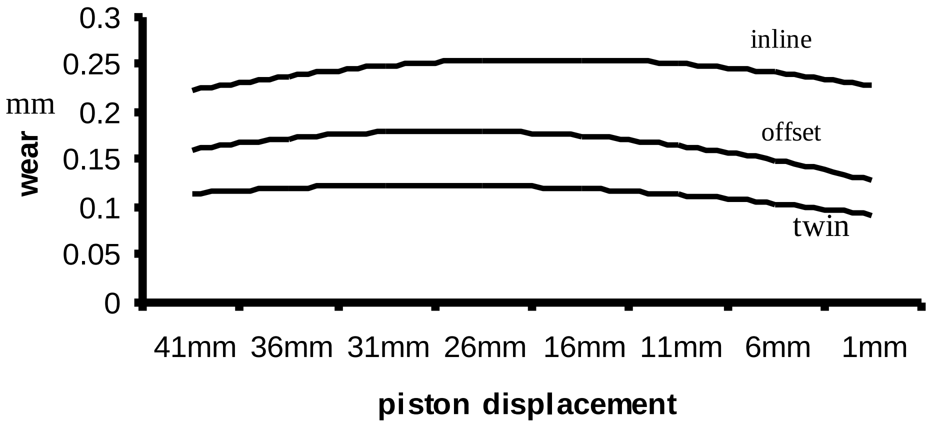


Figure 13: liner wear comparison between the inline, offset and twin crankshaft engines

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