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Impact Of Non Axial Crankshaft Mechanism On The Engines Performance

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***Abstract*—This study serves to evaluate the use of non axial crankshaft mechanism in diesel engines, in order to increase the power and to find the optimal values of displacement, that can be used. Currently in internal combustion engines are widely used axial crankshaft mechanism.**

To perform the study it is used theoretical methods of dynamic study of non axial crankshaft mechanism, compared with that axial. The study is received for a diesel engine cylinder of tractor T75, for which is obtained engine indicatory diagrams and parts mass of crankshaft mechanism. For given engine, it is calculated inertia force on the piston node, total force and finally tangential force on crank and engine torque created for unit of the piston surface.

The results of the calculations show, that the inertia forces for non axial crankshaft mechanism differ little from axial mechanism, indicating that loads in pin and rod journals and main journals are the same. While tangential force and the engine torque grow with increasing of the relative displacement. This increase goes in 1.8 and 3% for relative displacement values of 0.1 and 0.2, while for the value of relative displacement 0.3 and 0.4 it runs in 5 and 6.7%. In addition non axial crankshaft mechanism, the piston displacement increases over 1%, which leads to an improvement of the combustion process, in increasing the engine volume and engine power. In conclusion, it is recommended the use of non axial crankshaft mechanism in vehicle engines, because currently with the use of electronic systems, the regulation of advances problems are solvable. While from this use, we obtain the reduction of fuel consumption and environmental pollution.

Keywords—Non axial crankshaft mechanism; engine torque; power.

I. INTRODUCTION

The crankshaft mechanism is the main mechanism of engine, which is widely used in vehicles, and other sectors. Analysis of dynamic study of engine crankshaft mechanism [1] shows that in the engine power, affects the force acting on the piston, but also the type of mechanism. Crankshaft mechanism can be axial, where the axis of the cylinder is intersected to axis of crankshaft and non axial, where the axis of the cylinder is displaced by the axis of crankshaft. Currently in vehicle engines used axial crankshaft mechanism, because the practice of advances placing in the camshaft and high pressure fuel pump is difficult. For reduction of piston shocks during passage through TDC, in some engines, it is used the displacement of the pin axis against to the cylinder axis, which brings reduction of noise in engine. It is recommended (0.015-0.035) S [2],[3].

Numerous studies and experiments for increasing the performance of engines mainly related to the perfection of the fuel system [4,5], and in constructive aspect related to improving the shape of the combustion chamber in the piston and in engine head, as well as improving manufacturing technology for increasing the quality of details, in order to expand of their engine durability.

From the dynamic study of the crankshaft mechanism of engines [1],[2] it is shown that on created torque, besides the forces of the gases pressure and the inertia forces of translational masses, affects also the β angle, that forms the connecting rod with the axis of the cylinder, which for non axial mechanism it is not equal for compression stroke and firing stroke, as at axial mechanism. For this reason we get to study this effect by defining and the object of our study that is evaluating the impact of non axial crankshaft mechanism on engines performance in order to increase of their power. In the study for numerical implementation of gas pressure on the piston and mass of rod crank mechanism, it is taken the cylinder of diesel engine tractor T75. This study is important because it is connected with the increase of engine power, the reduction of fuel consumption and environmental pollution.

II. MATERIALS AND METHODS

On crankshaft mechanism of vehicle engines act inertia forces of mass, gas pressure forces, weight forces and the friction forces. The most important loads acting on the piston are inertia forces and pressure gases forces, which change size and direction, creating on engine details fatiguing loads and vibrations [4], [5]. In our study we would neglect the friction forces and weight forces , because they remain constant and the study has comparative character. The used method is analytical, through the dynamic study of crankshaft mechanism. The inertia forces acting on the crankshaft mechanism are inertia forces of translational masses, which acts on the piston and the inertia force of rotating masses, which act in the direction to the crankshaft axis and does not affect at the engine power, therefore it will not treated.

So early it is done the determination of the inertia forces, acting on the piston, on the basis of calculating the parts mass of the mechanism. Then determining the gas pressure force and the total force on the piston, from which is determined the tangential force in crank and torque. To draw general conclusions for diesel engines, calculations of forces and moments are made for specific power, to one cm^2 of the piston area.

In engineering design practice of engines [1],[3], the displacement of the cylinder axis must be by the rotation of the crankshaft and it is used relative displacement k= e/R, which recommended 0.2 to 0,3 [3], because the connecting rod meet on the cylinder walls. According to the method the calculations of forces and momentum are performed for 36 crankshaft positions for axial mechanism (k= 0) and non axial mechanism, for some value of relative displacement (k), 0.1, 0.2, 0.3 and 0.4. For numerical results are taken the parts of the crankshaft mechanism of tractor engine T75.

A. *The Inertia Force of Translational Mass*

The scheme of non axial crankshaft mechanism shown in fig. 1. The piston displacement from TDC (top dead center) calculated [1]

$$s = R\{\sqrt{\left(\frac{1}{\lambda}+1\right)^2 - k^2} - (\cos\propto + \frac{1}{\lambda}\cos\beta)\} \qquad (1)$$

Where: *R sin α =L sin β +e*

Sin β= λ (sin α - k) (2)

And

$$Cos\beta = \sqrt{1 - sin^2\beta} = (1-\lambda^2(\sin\propto - k)^2)^{1/2}$$

By using the two of first terms of the binomial series we take:

$$Cos\beta = 1 - \frac{\lambda^2 k^2}{2} - \frac{\lambda^2}{4} + \lambda^2 k \, sin\propto + \frac{\lambda^2}{4}\cos 2\propto \qquad (3)$$

After several calculations it results:

$$S = R\{\sqrt{\left(\frac{1}{\lambda}+1\right)^2 - k^2} - (\cos\propto + \frac{1}{\lambda} - \frac{\lambda k^2}{2} + \lambda k sin\propto - \frac{\lambda}{4} + \frac{\lambda}{4}\cos 2\propto)\} \qquad (4)$$

Piston position at TDC is determined by the angle α_1 and the angle (180+ α_2) in BDC, which defines:

$$\sin\propto_1 = \frac{e}{L+R} = \frac{\lambda k}{1+\lambda} \qquad (5)$$

$$\sin\propto_2 = -\frac{e}{L-R} = -\frac{\lambda k}{1-\lambda}$$

By derived two times the formulas 4, we take the acceleration of the piston

$j = R\omega^2 (Cos\ \alpha + \lambda \cos 2\alpha + \lambda k \sin \alpha)$

Where :

R - crank radius

ω - angular velocity in rad /sec

λ = R/L.

mj – reduced mass of rectilinear movement, which is calculated:

$$m_j = m_p + m_{bj}$$

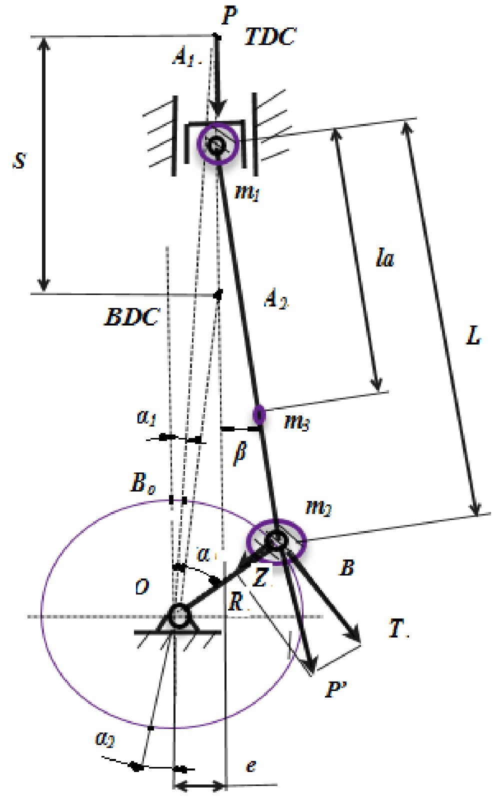

Fig. 1. *The scheme of non axial crankshaft mechanism.*

The inertia force of translational mass can be calculated :

$P_j = - m_j R\, \omega^2 (\cos \alpha + \lambda \cos 2\alpha + \lambda k \sin \alpha)$ (6)

Where:

m_p - is the mass of the piston node, in which included mass of the piston, the compression rings, the oil rings, the piston pin with stopper and the bronze bushing in rod, which for the taken engine in the study are given in table I [6].

Denomination workpiece	Quantity	Mass in kg
Aluminum piston	1	2.47
Compression ring	4	0.16
Oil ring	2	0.11
Piston pin with stopper (Φ48)	1	0.88
Bronze bushing in rod	1	0.244
Rod with caps, bolts and rod bearings	1	5.74

TABLE I. THE PART MASS OF THE PISTON ROD CRANK MECHANISM OF ENGINE T 75

m_{bj} –constitutes the reduced mass of rod plan movement. To complete dynamic equivalence, the replacement system consists from 3 mass: m_1 located at piston pin, m_2 at the rod journal and m_3 at its mass centre (Fig. 1), which must fulfill the requirements [1], [6]:

- To have the same mass
- To have the same mass centre

- To have the same inertia moment

From calculations, it shows that mass m_3 is very little, so it neglected and it is used the two first conditions, which expressed:

$$m_b = m_1 + m_2$$

$$m_1 l_a = m_2 (L - l_a) \qquad (7)$$

Mass of translational movement of rode:

$$m_1 = m_{jb} = m_b \frac{L - l_a}{L}$$

Dimensions of crankshaft mechanism in mm					
Dp	*R*	*L*	*la*	*λ*	*ω rad/sek*
125	*76*	*330*	*247*	*0.23*	*157.08*

TABLE II. DIMENSIONS OF CRANKSHAFT MECHANISM

Based on the mass and the size of the rod crank mechanism of the engine T 75 data in table I and table II, we take:

m_p=3.86 kg, m_{jb}= 1.44kg and m_j= 5.3 kg .

B. The Gas Pressure Force

Gas pressure forces is determined starting, indicatory diagram of engine, built by thermal calculations, known in technical literature [2, 3]. By calculations made with the program "Dia" [6] for data of the tractor engine T75 (diesel engine with direct injection with N=75 hp, n = 1500 rpm, the compression rate ε = 16) are derived the pressure values for 36 positions of crankshaft (every 20^0 crankshaft rotation), which are given in table III.

Position	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Pressure DN/cm ^{2}	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.91	1.2	1.4
Position	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Pressure DN/cm ^{2}	1.85	2.73	4.7	10.1	26.4	48.5	60.6	35.6	17.4	10.4	7.2	5.6
Position	**25**	**26**	**27**	**28**	**28**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Pressure DN/cm ^{2}	4	2.9	2.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1

TABLE III. VALUES OF GAS PRESSURE

As the change of stroke and position TDC are very small and timing of fuel injection lasts more, we use the values given for axial mechanism. So gas pressure forces acting on the piston will be calculated:

$$Pg = 9.8(p_g - p_o)\, Fp \qquad (N) \qquad (8)$$

Where:

p_o - is the pressure under piston, which for 4-stroke engines it is taken the same with atmospheric pressure, 1.033 DN/ cm^2.

C. Total Force and Engine Torque

The force acting on the piston for unit of piston area, will be calculated:

$$P = Pj/Fp + 9.8\,(Pg - 1.033) \qquad (N) \qquad (9)$$

Where:

$$Fp = \pi D^2/4 \qquad \text{in} \quad cm2$$

While tangential force acting in crank will be calculated (Fig. 1) [2],[6]:

$$T = P\,\frac{\sin(\propto + \beta)}{\cos\beta} = P\,\frac{\sin\propto \cos\beta + \cos\propto \sin\beta}{\cos\ \beta} \qquad (10)$$

By neglecting friction and weight forces, the engine torque , will be calculated:

$$M = T\,R \qquad (11)$$

Positive work of force T is calculated, when the created moment is by rotation sense of the crankshaft. In the interval (π-2π] and (3π- 4π], when the force P is positive, positive force T creates negative work, therefore in these intervals, it must do the change of force sign.

III. RESULTS AND DISCUTIONS

On the basis of formulas 6, 7, 9, 10, 11 are performed calculations of the inertia force, total force, tangential force T and torque for given crankshaft mechanism. Calculations are made for axial and non axial mechanism with relative displacement values k_1=0.1, k_2 =0.2, k_3 =0.3, k_4 =0.4 and displacement values for taken engine are e_1=7.6mm, e_2 = 15.2mm, e_3 = 22.8 mm and e_4 = 30.4 mm.

With results of calculations of the inertia forces for axial and non axial mechanism with k = 0.4 are built graphs for 36 crankshaft positions, which are shown in fig. 2.

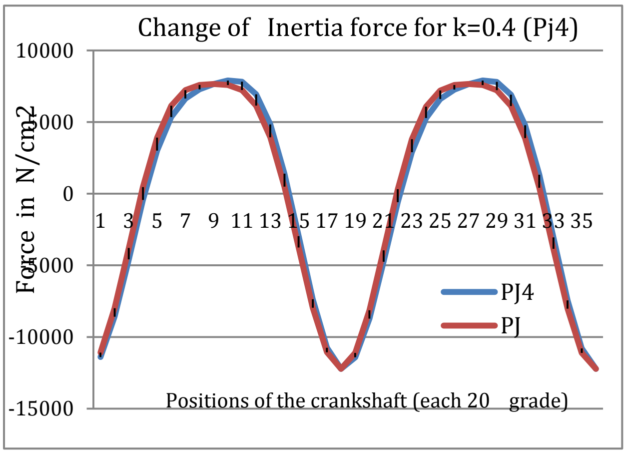

Fig. 2 *The inertia forces for axial and non axial mechanism with k = 0.4*

The results show that for the non axial mechanism the change of inertia force is small and the values displace to 20^0, according to the sense of crankshaft rotation. So negative maximum value is the same (12246 N), while the maximum positive value grows up a little from 7653 N to 7901 N (3%). This shows that increase of displacement does not effect on the increase of dynamic loads in the piston pin and the bearings of rod journal and main journal.

The calculation results of the force acting on the piston P and tangential force T, for k = 0.4 for 36 crankshaft positions are shown in fig. 3.

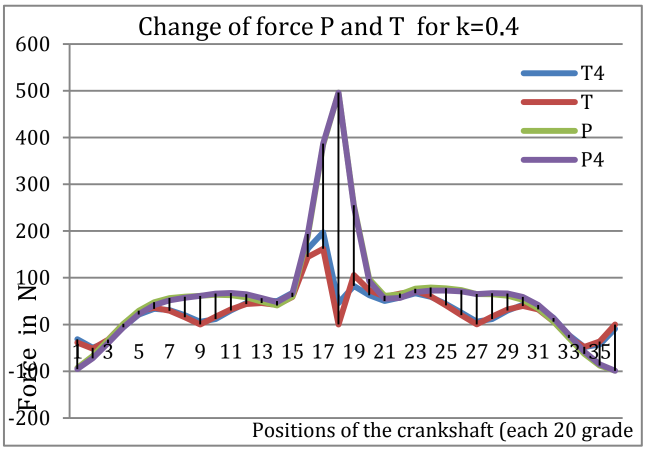

Fig 3 *The force on piston and tangential force for axial and non axial mechanism with k = 0.4*

The results show that for non axial mechanism, the piston force changes little by relative displacement. While tangential force increase in the total. The calculations results of created torque for axial and non axial mechanism with k = 0.4 for 36 crankshaft positions are shown in fig. 4.

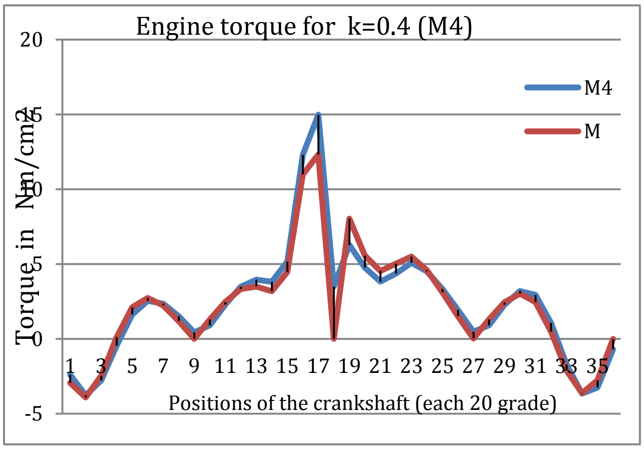

Fig 4 *Engine torque for axial and non axial mechanism with k = 0.4*

From calculations it is extracted the sum of tangential force and engine torque for 36 positions and average torque, depending on the relative displacement, which are shown in table IV:

Relative displacement	**K=0**	**K=0.1 e=7.6mm**	**K=0.2 e=15.2**	**K=0.3 e=22.8**	**K=0.4 e=30.4**
Sum of tangential force	1047.956	1066.967	1084.049	1101.155	1118.312
Sum of engine torque in Nm/cm2	79.64464	81.0895	82.38772	83.68776	84.9917
Average torque	4.305116	4.383216	4.45339	4.523663	4.594146
Increase of average torque in %	1	1.9	3.4	5	6.7

TABLE IV. THE VALUES OF TANGENTIAL FORCE AND ENGINE TORQUE BY RELATIVE DISPLACEMENT

From the table IV, it is shown that the sums of tangential force for 36 positions increase: for k = 0.1 with 19.1 N (1.8%) for k = 0.2 with 37.1 N (3.5%), for k = 0.3 with 57.2 N (5.4%) and for k = 0.4 with 70.3 N (6.7%). It also seems that growth of average torque by increasing displacement increase and can go up to 6.7%. Due to the touch of connecting rode on cylinder, optimum value of relative displacement is until 0.3, so that virtually increase of the torque can go to 5%. While increase of engine torque for non axial mechanism with k = 0.4, relatively axial is shown in fig. 5. It results that engine torque increase by increasing displacement and the great increase begins little more than 20^0 before TDC and achieve maximum with value to 3.4 Nm, for one cm^2 of piston surface.

For non axial mechanism are performed calculations for the angles α_1 and α_2, that determine extreme centers of the piston and the piston stroke, according to the formulas 4 and 5, which are shown in table V:

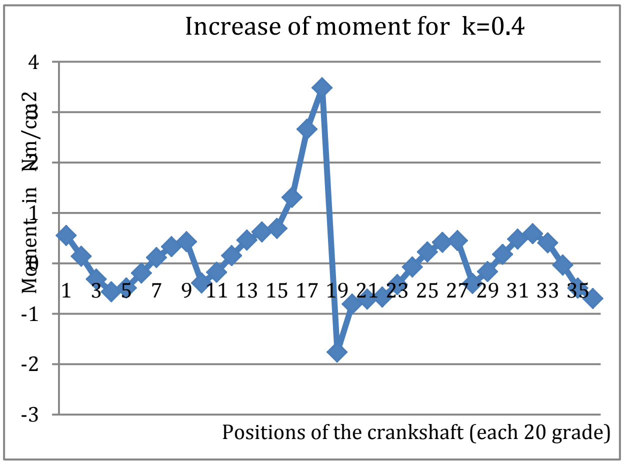

Fig 5 *Increasing engine torque for no axial mechanism with k = 0.4*

Relative Displacement k=e/R	0.05	0.1	0.2	0.3	0.4
α_1 (rad)	0.01	0.019	0.028	0.037	0.075
α_2	0.015	0.03	0.06	0.09	0.12
S	2.001 R	2.003 R	2.006 R	2.01 R	2.014 R

TABLE V. ANGLES OF EXTREME CENTERS OF PISTON AND THE PISTON STROKE

Thus for given engine with R =76 mm respectively for k = 0.2 and 0.3, the stroke increase with 0.45 mm and 0.76 mm, from which benefit increasing work volume and the engine power. While the piston speed is reduced near TDC, which improves the combustion process.

Non axial crankshaft mechanism used in engines has the disadvantage, that connecting rod touch the cylinder in downstream side by crankshaft rotation, especially in the case of cylinder with small diameter. This requires the cut of the cylinder for the high values of displacement. In practical terms of exploitation the use of non axial mechanism has had difficulty in problems of advances of camshaft and high pressure fuel pump. Nowadays with use of electronic systems for the regulation of advances, the use of engines with non axial mechanism serves as a way for the increase of power, reduction of fuel consumption and environmental pollution by vehicles.

IV. CONCLUSIONS

From the use of non axial crankshaft mechanism in engine, inertia forces and dynamic loads on piston pin, rod journal and main journal of crankshaft, remain the same as axial mechanism.

Using non axial crankshaft mechanism in the engine, can provide the increase of engine torques and power up to 6.7%, relatively axial mechanism.

Non axial crankshaft mechanism used in engines ensures the increase of piston stroke over 1%, from which we benefit the reduction of piston speed near TDC, improving the combustion process, increasing the displacement and engine power.

Non axial crankshaft mechanism used in engine is limited to engines with small cylinder diameter and requires changes in the cylinder construction

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