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CASE STUDY ON THE IMPACT OF PISTON NODE MASS ON DIESEL ENGINE PERFORMANCE

A. Hajderi and Sh. Gjevori

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Abstract: The study aims to analyze the importancethat have mass of the parts of the piston node in the dynamics and performance of the diesel engine under study. To obtain the results, the method of analytical study of the dynamics of the crank mechanism of the engine was used, where the forces acting on the piston and the specific moment per unit of the piston surface were determined. Calculations are performed for the actual mass of the piston node and for a reduction in the mass of the piston node by 10% and increases by 10% and 20%. The results show that for these measures, the change in motor torque is insensitive. In the case of a reduction in performance up to 0.01%, and with an increase of mass to 20%, we have an increase in performance by 0.02%. The influence of the mass of the piston node is pronounced on the inertial forces. By reducing the mass of the piston node by 10%, we have a reduction in inertia forces up to 11%, and by increasing the mass to 20%, we have an increase in inertia forces by 23%. This indicates that the dynamic loads on the piston pin on the rod bearing and on the bearing journals of the crankshaft are greatly increased, therefore diesel engine repair specialists must respect the dimensions of the piston node.

Keywords and phrases: Crank rod mechanism, diesel engine, piston node, the crank mechanism, the dynamic study.

1 Introduction

The crank mechanism is the main mechanism in the component mechanisms of engines, which are currently widely used in transport vehicles and other sectors. Despite all the criticisms made about this mechanism in relation to the masses, which perform rectilinear movement back and forth, no other type of thermal engine has been able to compete with its use in vehicle engines.

From the analysis of the dynamic study of the crank mechanism of engines [9, 10], [15], it results that the mass of translational movement of the mechanism consists of the mass of the parts of the piston joint, which make translational rectilinear movements and the reduced mass of the bell in the eye of the bell, which makes planar movements. In the engineering practice of engine design [10], [13, 14] the dimensions of the parts of the crank mechanism are given per unit of piston surface depending on the type of engine and the sectors of use, related to its rotations. These technical recommendations are derived from experimental engineering studies, which have taken into account ensuring the solidity of the details in accordance with the material used. This is because these parts work under difficult conditions of mechanical loads that act due to the high pressure of gases and the inertial forces of the mechanism's masses, but also of additional loads that arise due to the high temperatures at which they they work. In the given recommendations [1], [10, 13] (for the tractor engine are given g_p=25-35 kg/cm^{2}and g_b=30-55 g/cm^2), there is a large tolerance in the mass of the piston and that of the rode, ranging from 40 - 80%.

Meanwhile, in the process of assembling the parts of the crank mechanism of the engines, the manufacturing plants require small tolerances of the change in the dimensions of the piston node and the crankshaft between the engine cylinders, in order to ensure the external balancing of the engine

The piston assembly consists of the piston, the compression rings, the oil rings, the piston pin and its circlips or plugs. The piston in the early engines with small revolutions was made of gray cast iron and then, due to the improvement of the phenomenon of detonation, but also the increase of rotations, of cast aluminum alloy. The piston constitutes the main mass of the assembly. Un particular importance is the mass of the pinot, which during repairs in service centers can be increased due to the increase in the inner diameter of the piston pin, which is considered of little importance, but from practice, it is required to maintain the same mass in all cylinders. The connecting rod consists of the body, the eye of the rod, bronze bushing, the lower cap and the rod bearing. The rod body in early engines was made from mild steel by casting and then from special stamped steel, reducing its mass.

Numerous studies and experiments to increase the performance of engines are mainly related to the improvement of the fuel system [1, 2], [6, 8], while in the constructive aspect they are related to the improvement of the shape of the combustion chamber on the piston and the improvement of the production technology for increasing the quality of the parts, produced in order to increase their and the engine's lifespan and at the same time trying to reduce the weight of the engine per unit of motor power produced.

Based on the dynamic study of the crank rod mechanism of engines, it seems that in the work created during a cycle, in addition to the gas pressure forces, the inertial forces of the translational masses, which depend on the masses of these parts. Therefore, the object of *our study is focused on determining the influence of the mass of the piston node on the dynamics and performance of engines, with the aim increasing their performance, but also reducing the dynamic forces in the piston pin and in the rod bearings and the bearing journal of the crankshaft.* In this article, will be treated as a case study D75 diesel engine, whose parameters are given in Tab. 1 and 2 [2].

Table 1 Specification of the engine

Capacity	760 cc
Number of cilinders	4
Compression Ratio	14 :1
Maximum Torque	14.7 Nm for 1200
Maximum Power	75HP for 1500 rpm
Maximum gas pressure	60 bar

Table 2 Engine parameter

Connecting rod length (L)	330 mm
Crank radius (R)	76 mm
Piston diameter	125 mm
Stroke (S)	152 mm
Ratio of crank radius/ Connecting rod length λ =R/L	0.23
Shpejtesia kendore	157 1/sek

This study is important not only to show the influence of the mass of the piston joint as a whole on the dynamic performance of diesel engines, but also for the automotive service sector, where there is the possibility of changing the mass of the piston joint and more often of the piston pin.

2 Material and methodology

On the crank rod mechanism of the engines act the inertial forces of the moving masses, the gas pressure forces, the weight forces and the friction resistance forces. Of these, the most important loads acting on the piston are the force of inertia and the force of gas pressure, which change the value and direction, creating fatigue loads and vibrations in the engine parts [1, 2], [7, 10, 12]. In our study, friction forces and weight forces will be neglected, because they remain constant and the study has a relative character.

The method used in the study is analytical, through the dynamic study of the crank rod mechanism. The inertia forces acting on the crank rod mechanism are the inertia force of the translational masses, which acts on the piston, and the inertia force of the rotational masses, which acts in the direction of the axis of the crankshaft. This does not affect in the power of the motor, therefore the inertia force of the rotating masses will not be treated [9].

Thus, at the beginning, the inertia forces acting on the piston are determined, based on the calculation of the masses of the parts of the crank rod mechanism, then the pressure forces of the gases are determined, continuing with the determination of the total force on the piston, the tangential force in the crank and of the engine torque. Calculations are performed for 36 crankshaft positions for the given mass of the piston and for a reduction of it by 10% and an increase in the mass by 10% and 20%. For the concretization of the numerical results for the study, the masses of the crank rod mechanism parts of cylinder of a diesel engine D75 were taken. In order to have a more general discussion of the influence of the mass for diesel engines, the calculations of forces and operating moments were made for 1 cm^2 of the piston surface, in order to draw more general conclusions. The scheme of crank rod mechanism is given in Fig. 1.

Inertia force of translational masses. The inertia force of translational masses can be calculated (Fig. 1) [10, 4]:

$$P_j = -m_j R w^2 \left(\frac{\cos(\alpha+\beta)}{\cos\beta} + \lambda \; \frac{\cos^2\alpha}{\cos\beta} \right), (N) \tag{2.1}$$

or

$$P_j = -m_j R w^2 \left(\cos\alpha + \lambda \cos 2\alpha \right) = P_{i1} + P_{i2}. \tag{2.2}$$

Where:

$R-$ radius of crank in m;

$\omega-$ angular velocity in rad/sec;

$\lambda-$ – the ratio of the radius of the crank R to the length of the rod L;

m_j- the reduced mass of rectilinear movement, which is calculated:

$$m_j = m_p + m_{bj} \tag{2.3}$$

where:

m_p- is the mass of the piston joint, where included the mass of the piston, the compression rings, the oil rings, the piston pin with circlips and the broze bushing of the connecting rod, they are determined by weighing for the given engine and are given in Table 3 [2, 5];

$m_{bj}-$ is the reduced mass of the planar movement of the beam, which participates in the translational movement;

P_{i1}, P_{i2} first order inertia force and the second order inertia force.

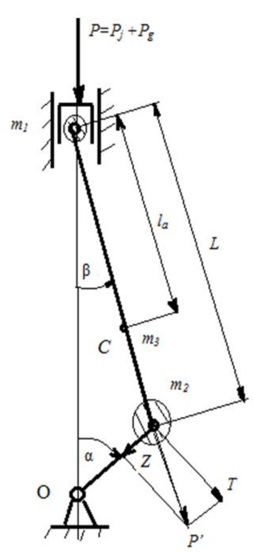

Figure 1. Scheme of the crank mechanism.

Table 3. Masses of the crank rod mechanism parts of the D 75 engine.

No.	Detail name	Amount	Mass in kg
1	Aluminum piston	1	2.47
2	Compression rings	4	0.16
3	Oil brings	2	0.11
4	Piston pin with circlips (Φ48)	1	0.88
5	Bronze bushing of the rod	1	0.244
6	The connecting rod with the cap, bolts and rod bearing	1	5.74

For complete dynamic equivalence, the replacement system of the rod consists of 3 masses: m_1 placed in the rod pin, m_2 at the rod bearing and m_3 at its mass center (Fig. 1), which must meet the conditions [2], [10]-[12]:

1. To have the same mass
2. To have the same mass center
3. To have the same inertia moment

Since the mass m3is very small from the calculations, it is neglected and the first two conditions are used, which are expressed as:

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

$$m_1 l_a = m_2(L - l_a). \tag{2.4}$$

From these equations, the mass of translational movement of the rod will be determined:

$$m_1 = m_{jb} = m_b \frac{L - l_a}{L} \tag{2.5}$$

The mass of translational movement of the crank rod mechanism will be calculated:

$$m_j = m_p + m_{jb} \tag{2.6}$$

Based on the masses given in table 3 and the dimensions in table 2 from equations (2.4) - (2.6)
have:

$$m_p = 3.86\ kg,\ m_{jb} = 0,144\ kg,\ m_j = 5,3\ kg.$$

For a given engine cylinder, based on formulas 2.1, the inertia force calculated is given in fig. 2.

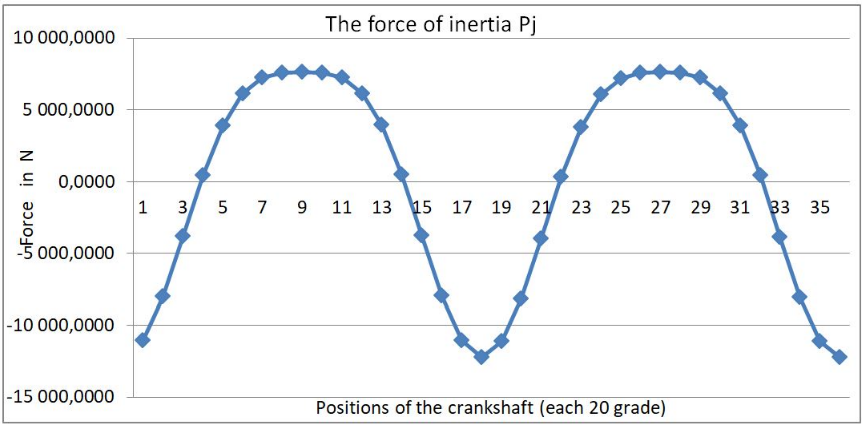

Figure 2. The inertial force of the translational mass of the D 75 engine.

The force of gas pressure. The force of gas pressure is determined starting from the indicator diagram of the engine, built according to thermal calculations, which are known in the technical literature [10], [13]. Thus, according to the calculations made with the "DIA" program [2] for the data of the D75 engine (Diesel engine with direct injection with N=75 kf, n=1500 rpm, compression ratio $\varepsilon = 14$), the values of gas pressure in DN/cm^2 for 36 positions of crankshaft (every 20^0 of crankshaft rotation), which are given in table 4 and the indicator diagram in coordinates P-φ is shown in Fig. 3.

Table 4

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

The force of gas pressure acting on the piston is calculated:

$$P_g = 10(p_{g-}p_o)F_p, \quad (N). \tag{2.7}$$

Where:

p_o- is the pressure in the crankcase, which for 4-stroke engines is equal to atmospheric pressure 1.033 dN/cm^2

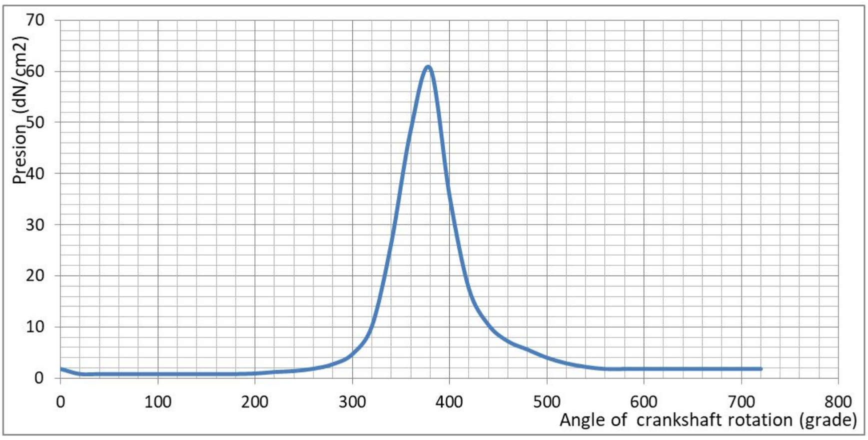

Figure 3. Extended indicator diagram of the D75 engine.

Work performed during a cycle. The force acting on the piston for 1 cm^2 surface of the piston will be calculated [2, 13]:

$$P = \frac{P_j}{F_p} + 10(P_j - 1,033), \quad (N) \tag{2.8}$$

Where: $F_p = \dfrac{\pi D^2}{4}$ *in cm*^{2}.

While the specific tangential force acting on the crank, which creates the engine torque will be calculated (Fig. 1) [2, 10]:

$$T = P\frac{\sin(\alpha + \beta)}{\cos\beta} = P\frac{\sin\alpha\cos\beta + \cos\alpha\sin\beta}{\cos\beta}, \quad (N) \tag{2.9}$$

Where:

$$\sin\beta = \lambda\sin\alpha, \quad \cos\beta = \sqrt{1 - (\lambda\sin\alpha)^2}.$$

The specific engine torque created and the specific work 1 cm^2 performed during one cycle of the piston, neglecting the frictional forces and the weights of the parts, will be calculated:

$$M = TR, \tag{2.10}$$

and

$$A = M\varphi = 2\pi TR.$$

The positive work of the force T is calculated when the created moment is according to the sense of rotation of the crankshaft (time sense). In the interval $(\pi - 2\pi)$ and $(3\pi - 4\pi)$ when the force P is positive, the extracted force T creates negative work, therefore the sign of the force T is changed in the calculations.

3 Results and discussions

Calculations of inertial forces were carried out based on formula (2.1) for 36 positions, for the given masses of the crank rod mechanism of the D75 engine and for the case of changing the translational movement mass values with a mass reduction by 10% (m_j= 4.77 kg), with a mass increase by 10% (m_j= 5.83 k), and with a mass increase by 20% (m_j= 6.36 kg) which are respectively P_j, P_{j2}, and P_{j4} and are shown in Fig. 4

From the calculations made, the maximum and average values of the inertia forces were determined with the change of the mass of the piston joint with a mass reduction by10%, with mass increase by 10%, and with mass increase by 20%, which are shown in Table 4.

Table 5

	Pj	Pj1 (-10%)	Pj2 (+10%)	Pj3 (+20%)
Average inertial force (N)	6295.3	5665.2	6923.6	7750.8
Maximum inertia force (N)	-12226	-11002	-13446	-14669

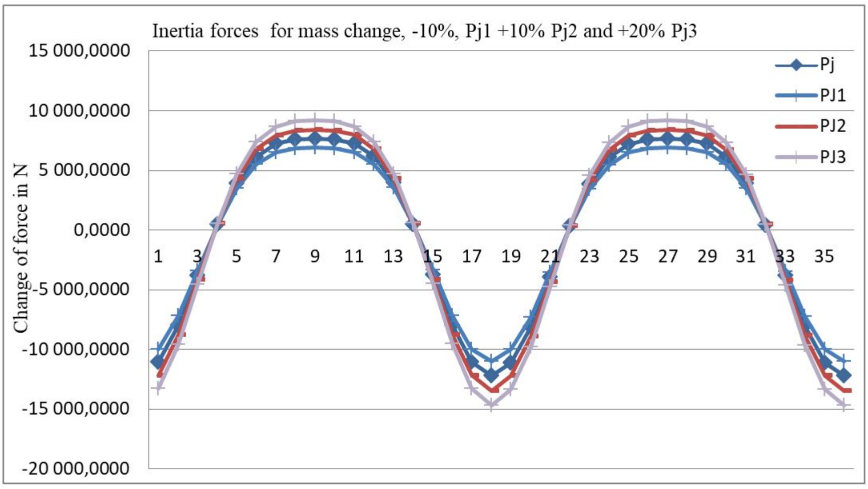

Figure 4. Inertia forces for mass changes -10% Pj1, +10% Pj2 and +20% Pj3.

The results show that the mass reduction of the piston joint by 10% causes a reduction of the maximum inertia forces by 1224 N, or 10%, and of the average values by 630N, or 11%. While the mass increase of the piston joint by 20% leads to an increase in the maximum inertia forces up to 2445 N, or 20%, and the average values by 1455N, or 23%. These dynamic loads act directly on the piston pin, on the rod and the rod bearing and bering journals of crankshaft. Meanwhile, we remember that from increase of number of revolutions increase a lot the dynamic loads.

While the calculations of the forces acting on the piston for 1 cm^2 were carried out on the basis of formula (2.7) for 36 positions, for the given masses of the crank rod mechanism of the

D75 engine and for the case of changing the values of the mass of the translational movement with a mass reduction of 10 % , with a mass increase 10%, and with a mass increase 20%, which are respectively P, P1, P2 and P3 and are shown in Fig. 5.

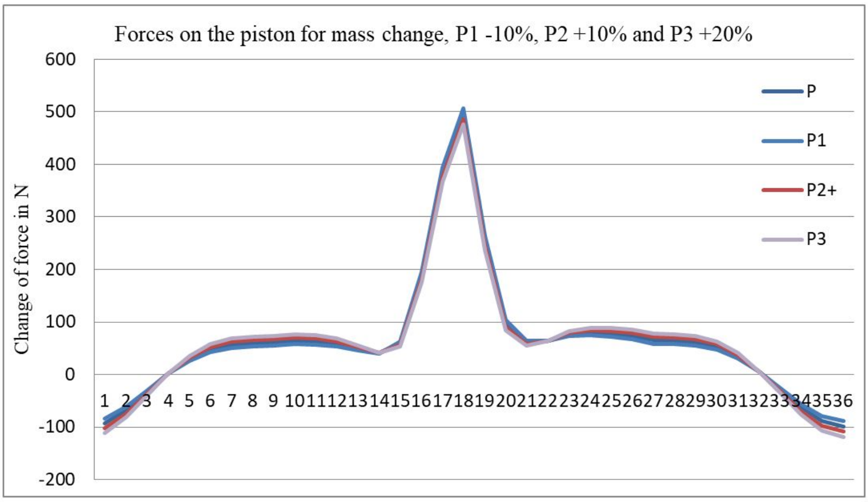

Figure 5. Forces on the piston for mass changes -10% P1, +10% P2 and +20% P3.

From the calculations made, the maximum and average values of the force acting on the piston with the change in the mass of the piston joint with a mass reduction by 10%, with a mass increase 10%, and with a mass increase 20% e were determined, which are shown in Table 6.

Table 6

	P	P1 (-10%)	P2 (+10%)	P3 (+20%)
Average force on piston (N/cm^2)	88.9	86.27	91.53	94.16
Maximum force on piston (N/cm^2)	496	506	486	476

The results show that reducing the mass of the piston joint by 10% leads to an increase a small decrease in the maximum force on the piston by 10 N/cm^2, or 2%, and a decrease in the average force by 2.6 N/cm^2, or 3%. This is related to the reduction of the maximum inertia forces. While increasing the mass of the piston joint by 20% leads to a decrease in the maximum force by 20 N/cm^2, or 4%, and a small increase in the average force on the piston by 5.26 N/cm^2, or 6%. As you can see, with the increase in mass, we have a decrease in maximum strength and an increase in average strength.

Similarly, the calculations of the tangential force acting on the crank for 1 cm^2 were performed based on formula (2.9) for 36 positions, for the given dimensions of the crank rod mechanism of the D75 engine and for the case of changing the values of the translational movement mass with reduction of mass 10%, with an increase of mass 10%, and with an increase of mass 20% which are respectively T, T1, T2 and T3 and are shown in Fig. 6

From the calculations made, the average values of the tangential force with the change of the mass of the piston joint with a mass reduction 10%, with a mass increase 10% and with a mass increase 20% were determined, which are shown in Table 6

Table 7

	T	T1 (-10%)	T2 (+10%)	T3 (+20%)
Average tangential force (N/cm^2)	29.110	29.1067	29.11363	29.11561

The results show that reduction of the mass of the piston joint by 10% leads to a very small reduction in the average force by 0.004 N/cm2, or 0.01%. While the increase in the mass of the piston joint by 20% leads to a very small increase in the average force by 0.006 N/cm2, or 0.02%
.

In the same way, the calculations of the engine torque per 1 cm^2 of the piston surface were

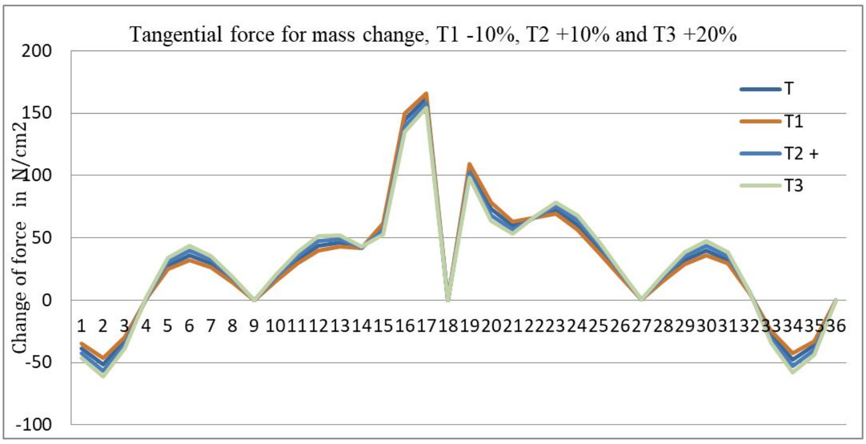

Figure 6. Tangential force for mass changes -10% T1, +10% T2 and +20% T3.

performed based on formula (2.10) for 36 positions, for the given mass of the crank mechanism of the D75 engine and for the case of changing the values of the translational movement mass with reduction of mass 10%, with mass increase of 10% and with mass increase of 20%, which are respectively MTR, MT1, MT2 and MT3 and are shown in Fig. 7

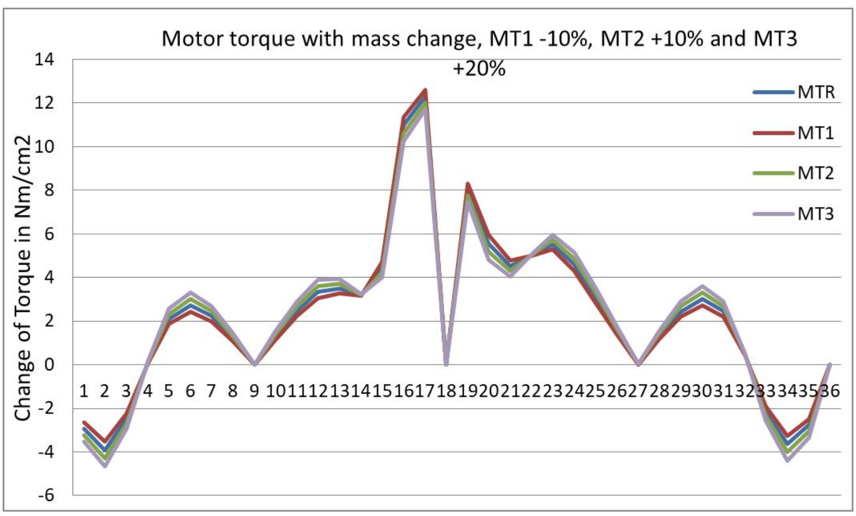

Figure 7. Engine torque for mass changes -10% MT1, +10% MT2 and +20% MT3.

From the calculations made, the average value of the engine torque was determined with the change in the mass of the piston joint with a mass reduction by 10%, with a mass increase by 10% and with a mass increase by 20% , which are shown in Table 8

Table 7

	MTR	MT1 (-10%)	MT2 (+10%)	MT3 (+20%)
Average engine torque (Nm/cm2	2.21234	2.21211	2.21256	2.212787

The results show that reducing the mass of the piston joint by 10% leads to a very small reduction in the average torque from 0.00023 Nm/cm^2, or 0.01%. While increasing the mass of the piston joint by 20% leads to a very small increase in the average motor torque by 0.00044 Nm/cm^2, or 0.02% . As seen from the decrease in the mass of the piston joint, there is a decrease in the average engine torque, and from the increase of mass, there is an increase in the average engine torque, contrary to what the specialists think.

So the results show that the influence of the mass on the increase in performance is very small and the increase in the mass of the piston joint leads to a very small increase in the performance of the engine. Meanwhile, it should be noted that the increase in the mass of the piston joint greatly affects in the increase of the dynamic loads on the piston pin, on the rod bearing and on the bearing journals of the crankshaft. This requires checking the solidity of the crank rod mechanism details and rebuilding the pin bronze bushing and rod bearing and the bearing journals of the crankshaft. Increasing the mass of the piston joint affects engine balancing problems, increasing engine rotations and increasing engine weight.

4 Conclusion

Following results are obtained in the article: Reducing the mass of the piston joint up to 10% causes a reduction of the maximum inertia forces by 1224 N, or 10%, and of the average values by 630N, or by 11%, greatly reducing the dynamic loads acting directly on the piston pin, on the rod bearing and on the bearing journals of the crankshaft. Increasing the mass of the piston joint up to 20% causes an increase in the maximum dynamic loads by 2445 N and the average values by 1455 N, causing a large increase in the maximum dynamic loads by 20% and the average values by 23%, which act directly on the piston pin, on the rod bearing and on the bearing journals of the crankshaft. Reducing the mass of the piston joint up to 10% causes a small increase in the maximum force on the piston by 10 N/cm^2 or 2% and the average value by 3% and the opposite happens with the increase in the mass of the piston joint by 20% . which results in a reduction of the maximum force by 20 N/cm2 or 4% and the average value by 6%.

The impact on engine performance of the mass of the piston joint is negligible. When the mass of the piston joint decreases by 10%, we have a decrease in the average tangential force and the average engine torque by 0.01%. While when the mass of the piston joint increases by 20%, we have a small increase in the average tangential force and the average engine torque by 0.02%.

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Author information

A. Hajderi, Department of Engineering, Albanian University, Tirana, ALBANIA.
E-mail: a.hajderi@albanianuniversity.edu.al

Sh. Gjevori, Institute of Transport, Ministry of Public Works and Transport, Tirana, ALBANIA.
E-mail: gjevorish@yahoo.com

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