

University of Wales Trinity Saint David

School of Engineering

CON-ROD

ACCELERATIONS, FORCES, DISPLACEMENTS

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1. Notation

1. $F_{gas_{max}}$: *Peak Gas Force*
2. R : *Crank Radius*
3. L : *Con – rod Length*
4. $F_{inertia}$: *Inertia Force*
5. $F_{net\ down}$: *Net Compressive Force*
6. $F_{net\ down_{max}}$: *Highest net Compressive Force*
7. σ_{p1} : *Maximum Compressive Stress in Production Engine*
8. σ_{m1} : *Maximum Compressive Stress in Modified Engine*
9. σ_{p2} : *Maximum Tensile Stress in Production Engine*
10. σ_{m2} : *Maximum Compressive Stress in Modified Engine*
11. E : *Young's Modulus*
12. Δx : *Changes in Con – rod Length*

2. Introduction

The report mainly put emphasis on the calculations and analysis of the accelerations, forces and displacements of the piston and con-rod assembly. The data which were applied in the calculations were based on the measurements of the engine components and test data from the Ford 1.6 Sigma engine. Referring to data for the production engine, the author modified the engine by changing the parameters value, which led to the changes of the con-rod accelerations, forces and displacements. The author used the Microsoft Excel[®] where large quantities of test data showed to carry out the calculations and plot graphs of changes in relevant forces and pressures. By comparing the changes and differences of two engines, the author could be able to analyze how the parameters of the con-rod influence the con-rod accelerations, forces and displacements.

3. Engine Components Data

The production engine and modified engine components data, which the report need to base calculations on, are showed on the table 3.1 below.

Table 3.1 Engine components data from production & modified engine

Type	Producton Engine	Modified Engine
Con-rod Mass	0.2674kg	0.2674kg
Conrod Cap Mass	0.1038kg	0.1038kg
Conrod Bolts Mass	0.03519kg	0.3519kg
Conrod Assembly Mass	0.4064kg	0.4064kg
Gudgeon Pin Mass	0.08022kg	0.08022kg
Piston Mass	0.2577kg	0.2577kg
Piston Ring Mass	0.00549kg	0.00549kg
Circlip Mass	0.00077kg	0.00077kg
Reciprocating Assembly Mass	0.3504kg	0.3504kg
Con-rod Length	0.134m	0.120m
Cylinder Bore	0.079m	0.082m
Crank Radius	0.0407m	0.0455m
UTS Con-rod	750 N/mm ²	750N/mm ²
Young's Modulus of Power Forged Steel	170000N/mm ²	170000 N/mm ²
Young's Modulus of Titanium	110000 N/mm ²	110000 N/mm ²

4. Peak Gas Force

Peak gas force could be calculated by the force equation below, by using the data from production and modified engine.

$$\text{Peak Gas Force} = \text{Peak Gas Pressure} * \text{Bore Area}$$

Peak gas pressure for the production and modified engine could be obtained from the data in excel.

For the production engine, the pressure is claimed to be 95.606 bar @18° atdc. @6000 rpm.

$$F_{gas_{max}} = \text{Peak Gas Pressure} * \text{Bore Area}$$

$$F_{gas_{max}} = 9560600 * \frac{\pi * 0.079^2}{4} = 46862.906 \text{ N}$$

For the modified engine, the pressure is 95.606 bar @18° atdc. @6000 rpm.

$$F_{gas_{max}} = \text{Peak Gas Pressure} * \text{Bore Area}$$

$$F_{gas_{max}} = 9560600 * \frac{\pi * 0.082^2}{4} = 50489.694 \text{ N}$$

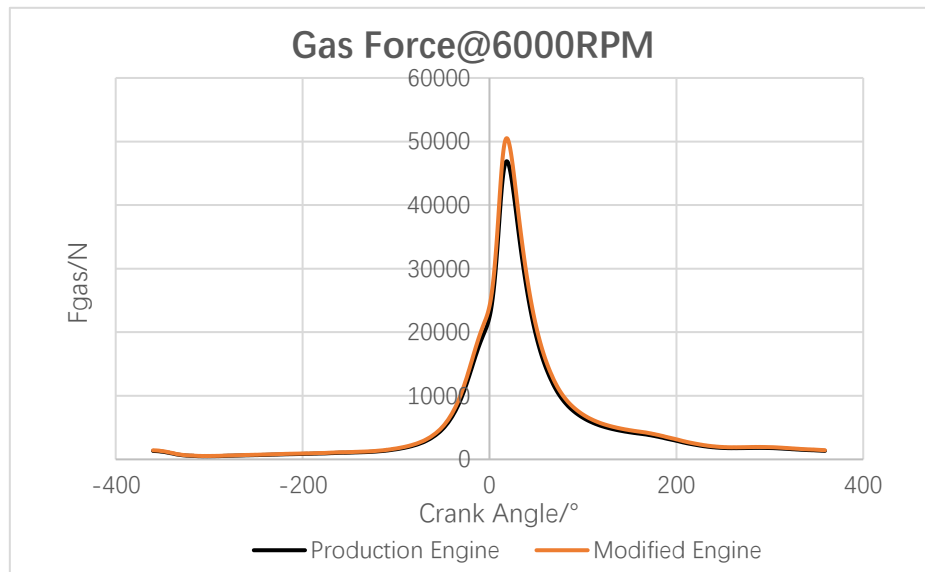


Figure 4.1 Gas Force@6000 rpm from production & modified engine

From the test data in excel the author found that the gas pressure increases as the RPM increase. And the peak gas force will appear in the “6000 rpm” conditions. The author chooses the graph of gas force at 6000RPM from production & modified engine to show that two engines have the similar trendline in gas force as the crank angle increase, but the peak gas force from modified one rises because of the increase of bore area.

5. Inertia Loads

Except the gas force, another force on con-rod called inertia force has a big influence on the performing of the reciprocating engine. The equation below shows the total inertia force, and the inertia force is composed of two forces, first order inertia force and second inertia force whose equations are also showed below.

For the total inertia force;

$$F_{inertia} = M_{piston}(R\omega^2 \cos\theta + (\frac{R}{L})R\omega^2 \cos(2\theta))$$

For the first order and second order inertia force;

$$First\ Order\ Inertia\ Force = M_{piston}R\omega^2 \cos\theta$$

$$second\ Order\ Inertia\ Force = M_{piston}(\frac{R}{L})R\omega^2 \cos(2\theta)$$

By calculating and analyzing the data in excel for every rpm from 1000 rpm to 6000 rpm, the author found the similar trendline, and the inertia force increase as the rpm increase by analyzing the equation. The author choose inertia force@6000 rpm to show on the report. And the Figure 5.1, 5.2, 5.3 demonstrate the total, first order and second order inertia force at 6000 rpm for the production & modified engine.

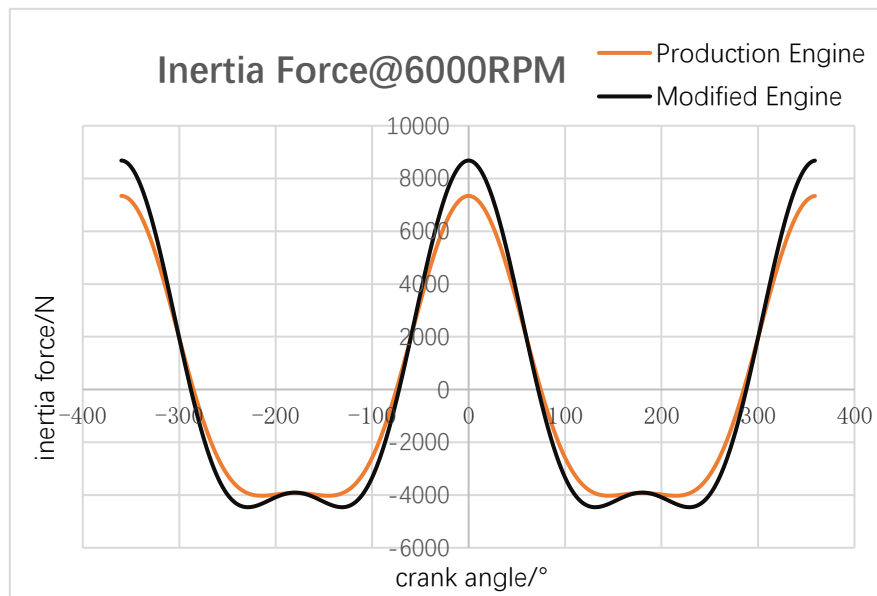


Figure 5.1 Total Inertia Force@6000 rpm from production & modified engine

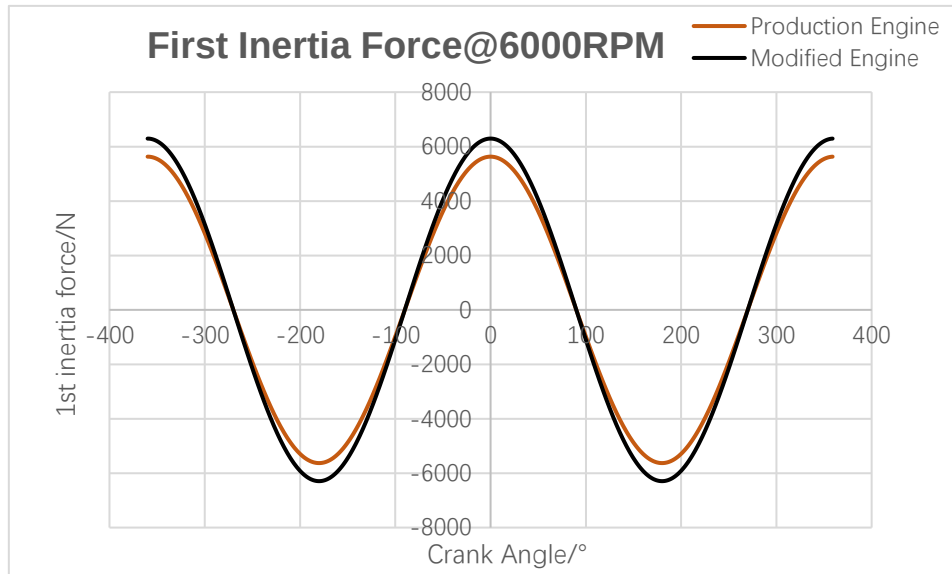


Figure 5.2 1st Inertia Force@6000 rpm from production & modified engine

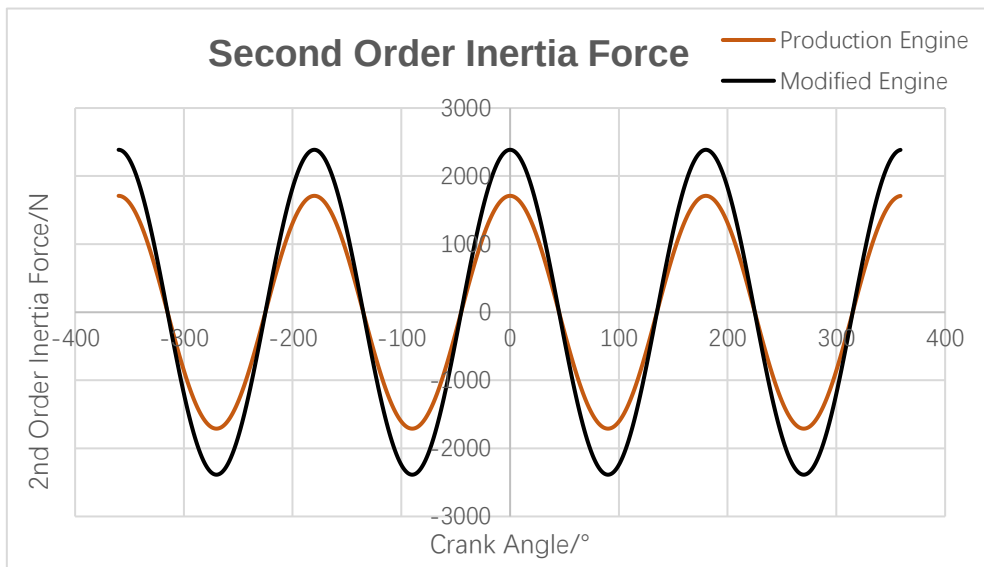


Figure 5.3 2nd Inertia Force@6000 rpm from production & modified engine

Compared with the inertia force on production engine, inertia force on modified engine shows a larger value in the light of the increase of crank radius and the drop of the rod length. Hence, piston mass, crank radius and rod length will affect the inertia force and the performance of the engine.

6. Highest Net Compressive Force on Rod

Net compressive force also can be called the net down force, which means that the piston is subjected to the compressive force when it moves downwards for combustion. And the piston is subjected to two forces, gas force and inertia force. Hence, the net compressive force can be calculated by the equation below;

$$F_{net\ down} = F_{gas} - F_{inertia}$$

For the highest net compressive force on rod,

$$F_{net\ down_{max}} = F_{gas_{max}} - F_{inertia@atdc}$$

When the author used excel to calculate the highest net compressive force for production engine, she found that the highest force showed at 5700rpm instead of 6000 rpm, which can be found in the graph below;

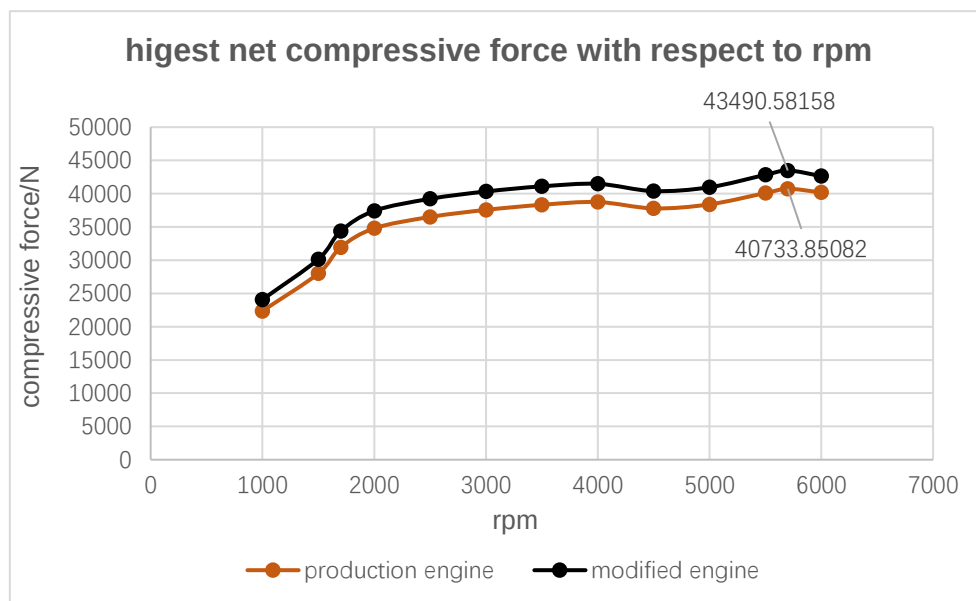


Figure 6.1 highest compressive force with respect to rpm from production & modified engine

From figure 6.1 above, highest net compressive force shows at 5700 rpm.

For production engine,

$$\text{highest net compressive force on rod} = 40733.85082N$$

For modified engine,

$$\text{highest net compressive force on rod} = 43490.58158N$$

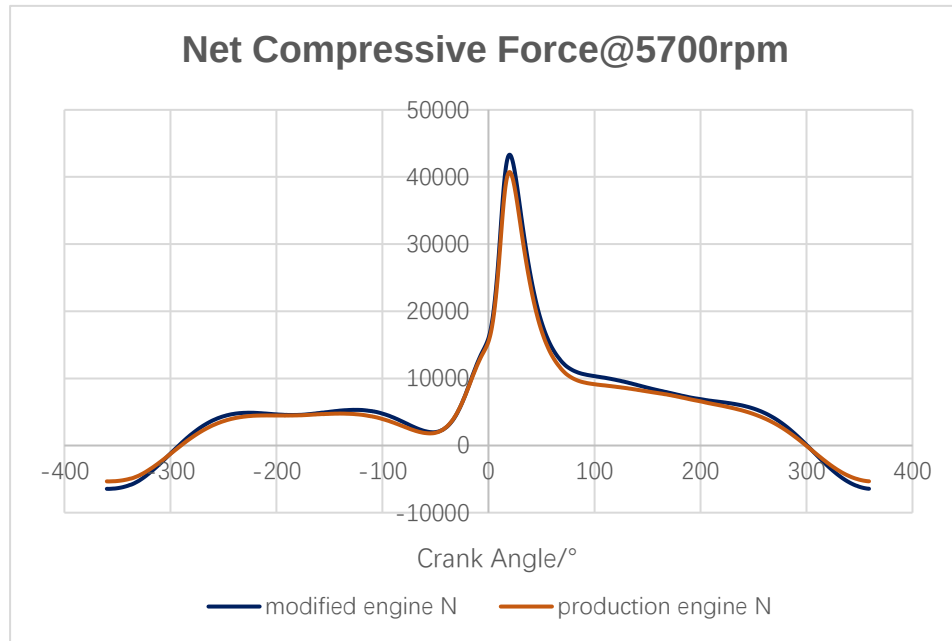


Figure 6.2 Net compressive force @5700rpm from production & modified engine

From the figure 6.2, the highest net compressive force at 5700rpm for modified engine is slightly higher than that for production engine.

7. Highest Net Tensile Load on Rod

Similarly, net tensile force also can be called the net up force, which means that the piston is subjected to the tensile force when it moves upwards. The equation below can calculate the highest net tensile force, when piston moves up to TDC, con-rod will be subjected to the highest force which also can be found in the figure 7.1 below.

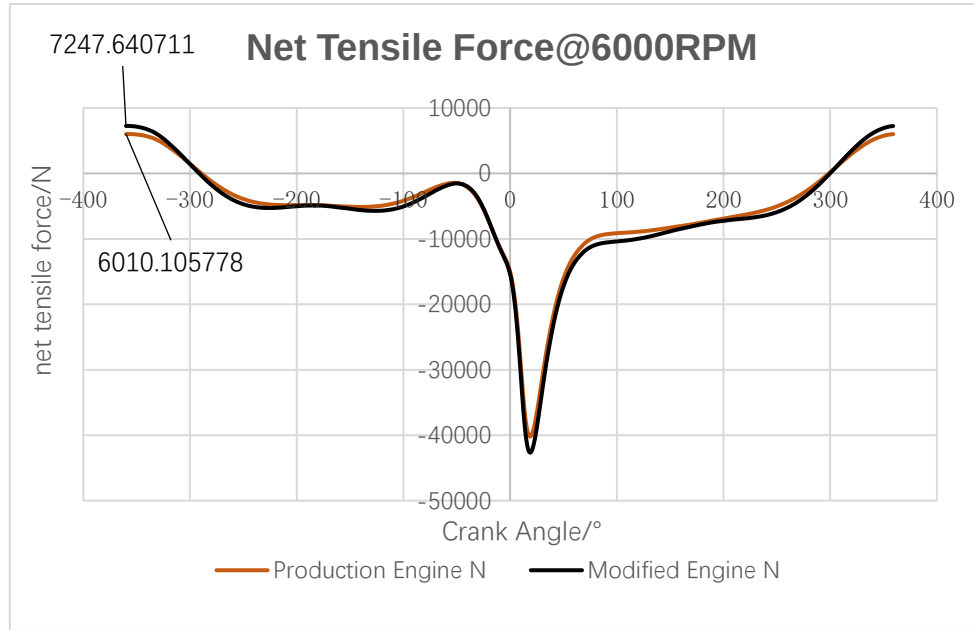


Figure 7.1 Net tensile force @6000rpm from production & modified engine

The author found that at 6000rpm the net tensile force can get the highest value. When piston moves to TDC, , and the equation can be rewritten as the equation shows below;

For the production engine,

$$\text{highest net tensile force} = F_{inertia}@TDC@6000RPM - F_{gas}@TDC@6000RPM$$

$$F_{inertia}@TDC@6000RPM = M_{piston}R\omega^2 \left(1 + \frac{R}{L}\right) = 7340.174N$$

$$\text{highest net tensile force} = 7340.174 - 1330.068 = 6010.106N$$

For the modified engine,

$$F_{inertia}@TDC@6000RPM = M_{piston}R\omega^2 \left(1 + \frac{R}{L}\right) = 8680.645N$$

$$\text{highest net tensile force} = 8680.645 - 1433.004 = 7247.641N$$

8. Maximum Compressive and Tensile stresses in Rod Shank

In order to calculate the maximum compression and tensile stresses in rod shank, firstly the data of the rod shank minimum cross-sectional area need to be measured. The rod shank cross-sectional area is a “I beam” area whose data are measured as the figure 8.1 shows;

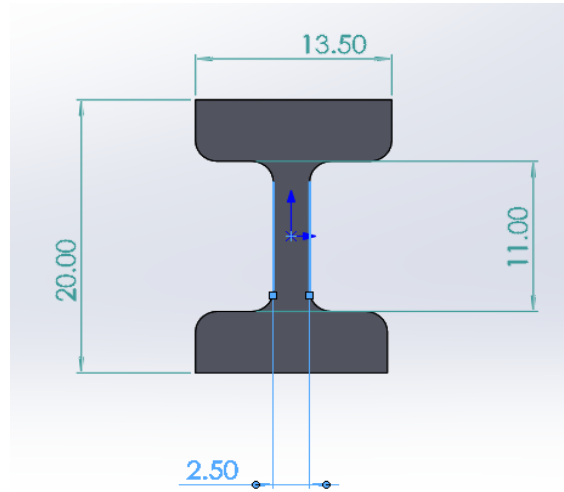


Figure 8.1 Data of the “I beam” rod shank cross-sectional area

Hence, cross – sectional area = $(13.5 \times 20 - 11 \times 11)mm^2 = 149mm^2$

8.1Maximum Compressive Stress

From pervious part, the maximum compressive force for production and modified engine has been calculated, and the maximum compressive stresses can obviously be calculated by using the equation below;

$$\sigma = \frac{F}{A}$$

For production engine,

$$\text{maximum compressive stress} = \sigma_{p1} = \frac{40733.85}{145} = 273.4N/mm^2$$

For modified engine,

$$\text{maximum compressive stress} = \sigma_{m1} = \frac{43490.58}{149} = 291.9N/mm^2$$

8.2Maximum Tensile Stress

Similarly, the maximum tensile stresses can also be resulted by the equation below;

$$\sigma = \frac{F}{A}$$

For production engine,

$$\text{maximum tensile stress} = \sigma_{p2} = \frac{6010.106}{149} = 40.34 \text{ N/mm}^2$$

For modified engine,

$$\text{maximum tensile stress} = \sigma_{m2} = \frac{7247.64}{149} = 48.64 \text{ N/mm}^2$$

In conclusion, for the engine, compressive stress shows considerably bigger effects on the performance of engine.

9. Nominal Static Safety Factors

Safety Factors could reflect the degree of structure safety which need to be applied in the engines to ensure the compressive and tensile force are all within the safe ranges. As the equation below shows, UTS(Ultimate Tensile Strength) of the con-rod is claimed to be 750N/mm² for forged steel.

$$\text{Safety Factors} = \frac{UTS}{\sigma}$$

For production engine,

$$\text{Safety Factors for compressive loads} = \frac{750}{273} = 2.75$$

$$\text{Safety Factors for tensile loads} = \frac{750}{40} = 18.75$$

For modified engine,

$$\text{Safety Factors for compressive loads} = \frac{750}{291} = 2.60$$

$$\text{Safety Factors for tensile loads} = \frac{750}{48} = 15.60$$

From the calculation, safety factors for tensile loads shows great bigger value than that for compressive loads, which ensures the entire safety in tensile deformations. And the modified engine shows a slightly decline of the safety factors but also in the safe ranges.

10. Maximum Compression Distance and Stretch

The beam between the big end and little end of the rod is assumed as a rectangle beam. UTS(Ultimate Tensile Strength) of the con-rod has been claimed to be 750N/mm² for forged steel, meanwhile, Young's Modulus of the steel is 170000N/mm². According to the definition of Young's Modulus, the author use equation below;

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\varepsilon} = \frac{\frac{F}{A}}{\frac{\Delta x}{L}}$$

The compression distance and stretch can be obtained by undergoing the deformation of the equation;

$$\Delta X = \frac{F * L}{E * A}$$

For the length of rectangle beam, the author needs to subtract the con-rod length from the radius of big end and little end. The diameters of the big end and little end are 24mm and 9mm.

For production engine,

$$\text{Length of rectangle beam} = 134 - 9 - 24 = 101\text{mm}$$

$$\text{compression distance} = \frac{40733.85 * 101}{170000 * 149} = 0.16\text{mm}$$

$$\text{Stretch} = \frac{6010.606 * 101}{170000 * 149} = 0.024\text{mm}$$

For modified engine,

$$\text{Length of rectangle beam} = 120 - 9 - 24 = 87\text{mm}$$

$$\text{compression distance} = \frac{43490.58 * 87}{170000 * 149} = 0.14\text{mm}$$

$$\text{Stretch} = \frac{7247.641 * 87}{170000 * 149} = 0.023\text{mm}$$

Changes in the length of the beam for modified engine has been shortened, because the change of rod length influences on it.

11.Changes in material – Titanium

In fact, Titanium con-rods, compared with steel con-rods, weigh less for reduced rotating and reciprocating weight, which may improve construction efficiency and aseismic performance.

By changing the material, Young's Modulus of Titanium is claimed to be 110000 N/mm². The calculation of the compression distance and stretch was showed below.

For production engine,

$$\text{compression distance} = \frac{40733.85 * 100}{110000 * 149} = 0.25\text{mm}$$

$$\text{Stretch} = \frac{6010.606 * 100}{110000 * 149} = 0.037\text{mm}$$

For modified engine,

$$\text{compression distance} = \frac{43490.58 * 86}{110000 * 149} = 0.23\text{mm}$$

$$\text{Stretch} = \frac{7247.641 * 86}{110000 * 149} = 0.037\text{mm}$$

Table11.1 Results of compression distance and stretch for two engines in steel and Ti

		Production Engine	Modified Engine
Steel	Compression distance	0.16mm	0.14mm
	stretch	0.024mm	0.023mm
Titanium	Compression distance	0.25mm	0.23mm
	stretch	0.037mm	0.037mm

Titanium alloy con-rods reduced the inertia mass of the con-rods because of the density of these two materials. The reciprocating inertia force of the rod can be reduced and also the velocity can increase, which can improve the performance of engine to some extent. From the table11.1, when using the identical design in Titanium, changes in length of con-rods are bigger than that in steel, which may result in a smaller valve clearance.

12. Conclusion

In this report, the author calculated and analysed the accelerations, forces, stresses and displacements of con-rod for two engines, which could provide a deeply understanding the knowledge of Con-rod. The author modified the engine by reducing the crank radius and increasing the cylinder bore and con-rod length. For the comparison between production engine and modified engine in results, the author found that modified engine got bigger inertia force, compression and tensile forces and stresses, but smaller compressive distance and stretch which affects the performance of the engine in vibration and velocity.

For the materials on con-rods, Titanium contributes to the lightness of the engine and high velocity or rpm which has been applied in the high race engines. However, its difficulty to process and the expensive price are also barrier to apply Titanium to the engine on market.

Reference

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