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Powder metal forged and C-70 Steel forged. Fatigue analysis of connecting rod

KEYWORDS: connecting rod, C70 Forged Steel, Powder Metal, Stresses and Strains.

A. Soufi
UFR Physics of Condensed Matter and Materials, Faculty of Sciences Ben M'sik, PO Box 7955, Sidi Othman, 20450 Casablanca, Morocco

K. Talea
UFR Physics of Condensed Matter and Materials, Faculty of Sciences Ben M'sik, PO Box 7955, Sidi Othman, 20450 Casablanca, Morocco

A. Bakali
UFR Physics of Condensed Matter and Materials, Faculty of Sciences Ben M'sik, PO Box 7955, Sidi Othman, 20450 Casablanca, Morocco

M. Talea
UFR Physics of Condensed Matter and Materials, Faculty of Sciences Ben M'sik, PO Box 7955, Sidi Othman, 20450 Casablanca, Morocco

B. Boubeker
UFR Physics of Condensed Matter and Materials, Faculty of Sciences Ben M'sik, PO Box 7955, Sidi Othman, 20450 Casablanca, Morocco

ABSTRACT *The connecting rod is a key element in the four-stroke engine. It connects reciprocating piston to rotating crankshaft, transmitting the thrust of the piston to the crankshaft. Connecting rods engine for automobiles are generally manufactured by two different processes: the steel forging and forging of the metal powder. Each forging process, steel or metal powder is characterized by its advantages and disadvantages. Approximately, 80% of the connecting rods in Europe are steel forged as opposed to 43% in North America. In order to recapture the US market, the steel industry has focused on development of production technology and new steels as C70. The connecting rod is generally manufactured for infinite life period and the model criterion has limited power. It is solicited by loads of compression, axial tension, multi-directional bending force of inertia and torque.In this work: First, we make a kinematics, dynamics and thermodynamics study, to determine the compressive and traction loads on the connecting rod. Secondly, we apply the loads on the two types of connecting rods Thirdly, using Mathematica, Cast3M and finite element method, we investigate and compare fatigue strength of C70 steel forged connecting rods with that of the powder forged connecting rods.*

1. Introduction

The connecting rod is a centerpiece in the block of four-stroke engine; it transmits the forces exerted by the piston to the crankshaft.

Associated with the crankpin of the crankshaft is obtained converting a reciprocating motion into a rotary motion continues. Therefore, the connecting rod is loaded by millions of repetitive cyclic action. These actions are mainly mass forces and forces of the combustion gases. The superposition of these two actions results in the appearance of the axial force that acts on the connecting rod (Sonsino, 1996).

The connecting rods are also solicited by bending moments resulting eccentricities, forces mass and rotation of the crankshaft. The axial load can be calculated by knowing the pressure and engine speed, while the bending moment can be determined by analyzing the stress in an engine.

Result of these efforts loads; every part of the connecting rod will be solicited differently8:

- The connecting rod small: tension and compression;
- the connecting rod big end: tensile, compression and bending;
- The connecting rod shank: tension, compression, bend ing and buckling.

The longer is the connecting rod, the better it transmits the force applied to it, this length is generally for engines slow or static around 4 ... 5 ... the radius of the crankshaft.

Shorter is the connecting rod faster is the rotation, the objective is to minimize the effects of inertial loads reciprocating or rotary, this length for fast engines is generally less than 3.5 times the radius of the crankshaft.

The stress analysis of the critical zones and the maximum stresses on the connecting rod, has shown that these critical areas are fragile and in the regions of transition between the connecting rod big end and The connecting rod shank , and between The connecting rod shank and The connecting rod small. Automobile manufacturers are always looking for new and better processes and economic cost.

Common technological processes for the production of connecting rods are forging, casting and forging metal powders.

Many recent publications have shown the benefits of using lightweight materials in the production of connecting rods: reduction of inertial forces, gain speed, durability and cost optimization. Torque control and speed instant internal combustion engine are crucial.

Today the experimental access to the dynamic characteristics of the engine is possible:

- Use of pressure sensors- Instantaneous measurement of torque

Unfortunately this technique is very expensive: because the number of sensors increases with the number of cylinders.

Using the two computer codes, Mathematica and Cast3M, we present in this paper a mathematical model based on the finite element numerical method to extract and compare the behavior of two connecting rods characterized by the same geometric data but produced by the following two processes:

- C70 forged steel
- And forged metal powder

The principal steps:
Presentation of two processes: forged steel and powder

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metal forged.

- Calculate kinematics and dynamics (speed, acceleration and dynamic loads)
- Mesh
- Application of loads
- Extraction of stresses, deformed and displacement
- Comparison
- Conclusion

The principal parts of a connecting rod:

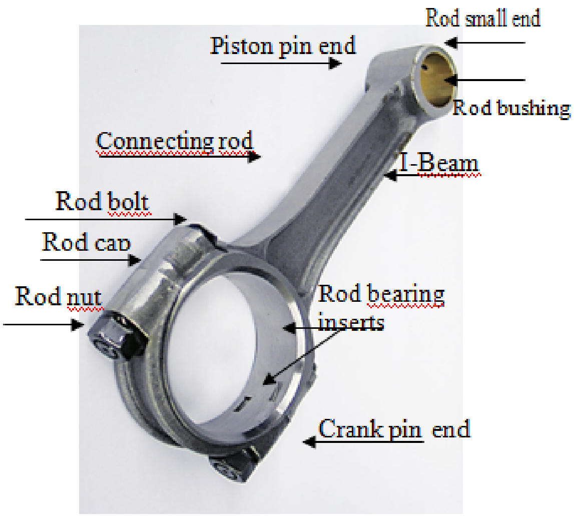

Fig.1: typical connecting rod

2. Comparison of Forged Steel and Powder Metal Connecting Rods

The principals three production processes of engine connecting rods are:

* the forging
* the casting
* and the metal powder forged

2.1 Forging

Forging is the process by which metal is heated and is shaped by plastic deformation by suitably applying compressive force. The forging operation can be carried out at room temperature (cold working) or at elevated temperatures. Forging offers a high strength–to-weight ratio, good toughness and resistance to impact and fatigue. Metals commonly used for forging include carbon steel, alloy steel, stainless steel, aluminium, copper, bronze, brass and magnesium.

Fig.2: Schematic showing the principle of forging a connecting rod

2.2 Powder Forging

Powder Metallurgy is a continually and rapidly evolving technology embracing most metallic and alloy materials, and a wide variety of shapes. PM is a highly developed method of manufacturing reliable ferrous and nonferrous parts.

Parts are created by mixing elemental or alloy powders, compacting the mixture in a die, and then heating or "sintering" the resultant shapes in a controlled- atmosphere furnace to bond the particles metallurgically.

Steps in powder metallurgy: Powder production, Compaction, Sintering, & Secondary operations

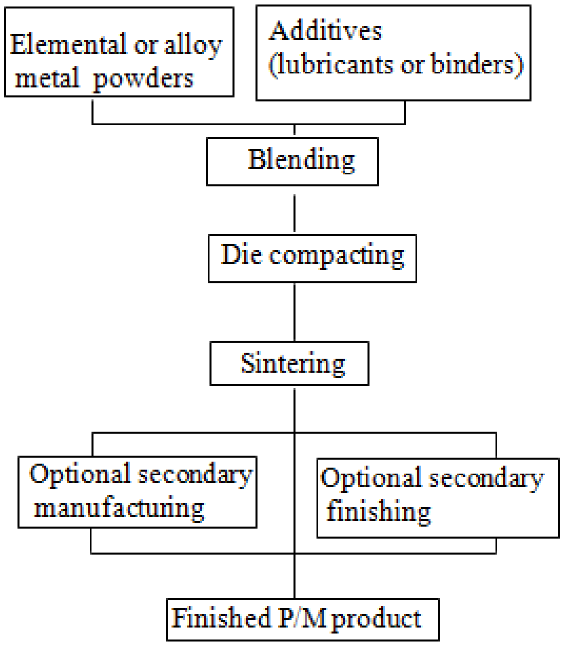

Fig.3: Simplified flowchart illustrating the sequence of operations in Powder Metallurgy process

3. Kinematics study
3.1 The connecting rod

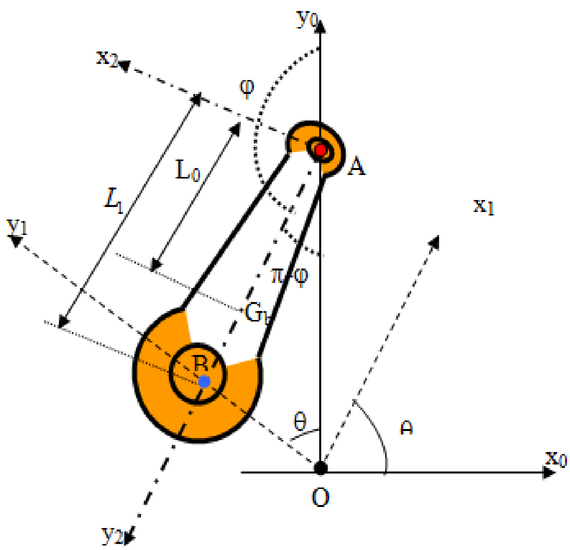

Fig.4 Schematic illustration movement of the connecting ro

Velocity and acceleration of center of gravity of the connecting rod:

In the absolute reference: $(\vec{e_{x_0}}, \vec{e_{y_0}}, \vec{e_{z_0}})$

Kinematics equation: $\begin{cases} r.\sin\theta = L_1.\sin\varphi \\ \sin\varphi = \frac{\sin\theta}{\delta} \end{cases}$

Using the kinematics equation: $\dot{\varphi} = \frac{\dot{\theta}.\cos\theta}{\delta.\cos\varphi}$

We obtain:

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$$\vec{v}_{G/R_0} = \begin{cases} -\dfrac{L_0.\dot{\theta}.\cos\theta}{\delta} \\ r.(\dot{\varphi}-\dfrac{L_0}{L_1}.\dot{\varphi}-\dot{\theta}).\sin\theta \\ 0 \end{cases}$$

$$\vec{\gamma}_{G/R_0} = \begin{cases} \dfrac{L_0.\dot{\theta}^2.\sin\theta}{\delta} \\ r.\dot{\theta}.\left(\dot{\varphi}-\dfrac{L_0}{L_1}.\dot{\varphi}-\dot{\theta}\right).\cos\theta + r.\ddot{\varphi}.\left(1-\dfrac{L_0}{L_1}\right).\sin\theta \\ 0 \end{cases}$$

3.2 The piston

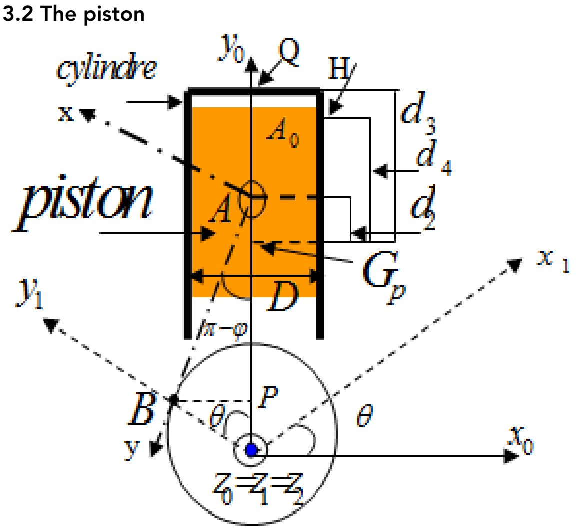

Fig5. Schematic illustration the alternating movement of the piston

During the rotation of the crankshaft the crankpin, the position of the piston is determined by the segment AA_0, A_0 position corresponding to the top dead center TDC abbreviation. TDC is the point at which the piston reaches its uppermost position in the cylinder.

$$AA_0 = r.((1-\cos\theta)+(1+\cos\varphi)) = r.\left(1-\cos\theta+\delta.(1-\sqrt{1-\frac{\sin^2\theta}{\delta^2}})\right)$$

To the order 2 :

$$\begin{cases} AA_0 = r.\left(1-\cos\theta+\dfrac{\sin^2\theta}{2.\delta}\right) = f_1(\theta)+f_2(\theta) \\ f_1(\theta) = r.(1-\cos\theta) \\ f_2(\theta) = r.\dfrac{\sin^2\theta}{2.\delta} \end{cases}$$

Expression that is composed of two terms: one first

$f_1(\theta) = r.(1-\cos\theta)$ in first order and

a second $f_2(\theta) = r.\frac{\sin^2\theta}{2.\delta}$ second order.

Graphic illustration using the mathematica code: For: $\delta = 4$

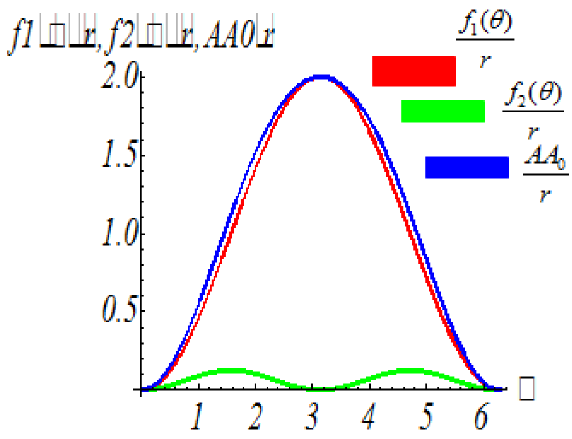

Fig.6: Red curve representing the first term and the green curve representing the 2nd term according to the crankshaft angle

$AA_{0\max} = 2.r$: represents the distance between the bottom dead center BDC and the top dead center TDC.

For $\theta = \frac{\pi}{2}$; $\frac{AA_0(\theta=\frac{\pi}{2})}{r} = 1.125\rangle 1$

Already the piston moves more than its course limited by TDC and BDC points. And:

$$\frac{AA_{0\max}}{\frac{2r}{2}} = 56.25\%\rangle 50\%$$

For more precision, calculations are pushed up to order 4.
We have three terms:

- The first term of order 1: $f_1/r = 1-\cos\theta$
- The second term of order 2: $f_2/r = \frac{\sin^2\theta}{2.\delta}$
- And the third term of order 4: $f_3/r = \frac{\sin^4\theta}{8.\delta^3}$

Graphically: always with $\delta = 4$

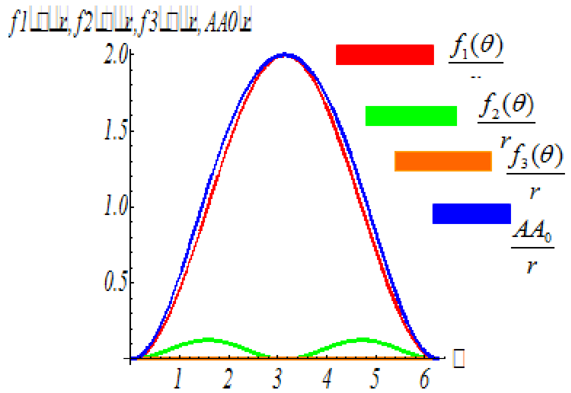

Fig.7: Red curve representing the first term, the green curve representing the 2nd term and the orange curve representing the third term according to the crankshaft angle

We obtain similar results, so the order 2 is largely sufficient.

*** The piston velocity:**
At the order2:

$$v_p = \frac{dOA}{dt}/R_0 = \frac{-L_1.\dot{\theta}}{\delta}.\left(1+\frac{\cos\theta}{\delta}\right).\sin\theta$$

By hypothesis it is assumed that the angular velocity is con-

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stant: $\omega = \dot{\theta} = cte$

Engine to full throttle:

$$\begin{cases} \omega = ntr/\min \\ n = 2000 \\ \omega = \dfrac{\pi.n}{30} rad/s \\ \dfrac{\pi.n}{30} = 209.44 \end{cases}$$

engine to full throttle

Graphic representation of the piston velocity

$$\frac{v_p}{L_1} = \frac{-\dot{\theta}}{\delta}.\left(1+\frac{\cos\theta}{\delta}\right).\sin\theta = \frac{-209.44}{4}.\left(1+\frac{\cos\theta}{4}\right).\sin\theta$$

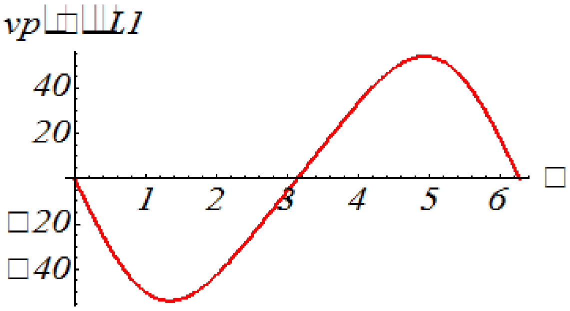

Fig.8: curve of the piston velocity

Graphically:

- the piston velocity is maximum when θ is near $\frac{\pi}{2}$ or . $\frac{3.\pi}{2}$
- null at points (TDC) and (BDC)

By calculation, we can find values that maximize the velocity of the piston:

$$\theta_1 = arc\cos\left(-\frac{\delta}{4}+\sqrt{\left(\frac{\delta}{4}\right)^2+\frac{1}{2}}\right) = 77.01°$$

in the triangle OAB: $\hat{O}+\hat{B}+\hat{A} = 180°$, $\hat{O} = \theta$

$$\sin\hat{A} = \sin(\pi-\varphi) = \sin\varphi = \frac{\sin\theta}{\delta} = \frac{\sin 77.01}{4}$$

$$\Rightarrow \quad \hat{A} = 14.098°$$

then: $\hat{B} = 180 - \hat{A} - \hat{O} = 180 - 77.01 + 14.098 = 88.89 = 90° = \frac{\pi}{2}$

Conclusion:
When the velocity of crank and connecting rod system is maximal: the connecting rod is normal to the direction of the crankshaft the crankpin

**** The acceleration of the piston:**
By differentiating the velocity we get:

$$\frac{\gamma_p}{r} = \frac{d\frac{v_p}{r}}{dt} = -\dot{\theta}.\frac{d\left(1+\frac{\cos\theta}{\delta}\right).\sin\theta}{dt} = -\omega^2.\left(\cos\theta+\frac{\cos 2\theta}{\delta}\right) = \frac{\gamma_1}{r}+\frac{\gamma_2}{r}$$

$\frac{\gamma_1}{r} = -\omega^2.\cos\theta$ first-order term

$\frac{\gamma_2}{r} = -\frac{\omega^2.\cos 2\theta}{\delta}$ acceleration term of order 2

Graphic illustration for: $\delta = 4$, $\omega = 209.44 rad/s$

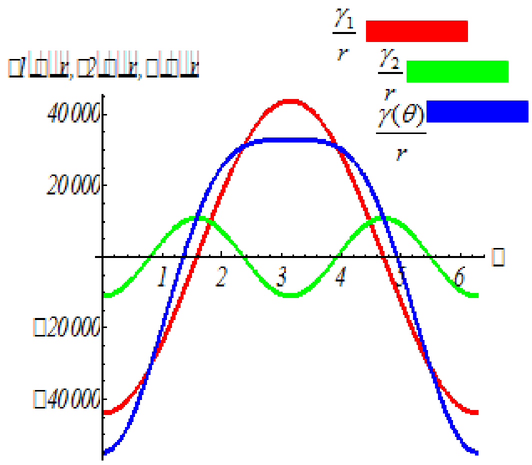

Fig.9: curve of the piston acceleration

The maximum acceleration: $\frac{\omega^3}{\delta}.\left(\sin\theta+\frac{2.\sin 2\theta}{\delta}\right) = 0$

$\Rightarrow \sin\theta = 0$ or $\cos\theta = \frac{-\delta}{4}$

$\sin\theta = 0 \Rightarrow \theta = 0$ (TDC) or $\theta = \pi$ (BDC)

$\cos\theta = \frac{-\delta}{4}$: if $\delta \rangle 4$ θ physically does not make sense;

$\delta \langle 4 \Rightarrow \theta = \arccos(\frac{-\delta}{4})$

For : $0 \langle \delta \langle 4$

$$\frac{\gamma_{max}}{L_1} = \frac{\omega^2}{\delta^2}.\left(\frac{\delta^2}{8}+1\right) \Rightarrow \frac{\gamma_{max}}{r} = \frac{\omega^2}{\delta}.\left(\frac{\delta^2}{8}+1\right)$$

Graph of $\frac{v_{p\max}}{r}$ **and** $\frac{\gamma_{\max}}{r}$ **:**

$$\left|\frac{v_{p\max}}{r}\right| = \dot{\theta}.\left(1+\frac{\cos 77°}{\delta}\right).\sin 77°$$

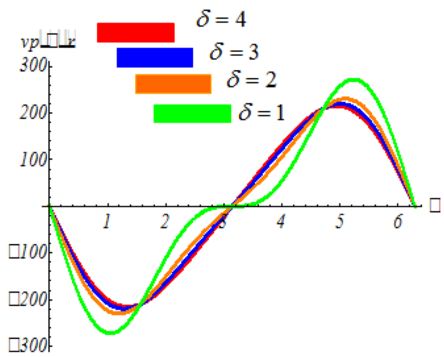

Fig.10: curve of the piston velocity/for different values of δ

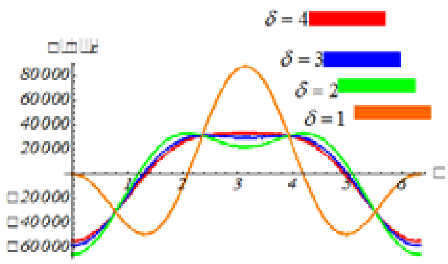

Fig.11: curve of the piston acceleration /for different values of δ

Fig.11: curve of the piston acceleration /for different values of δ

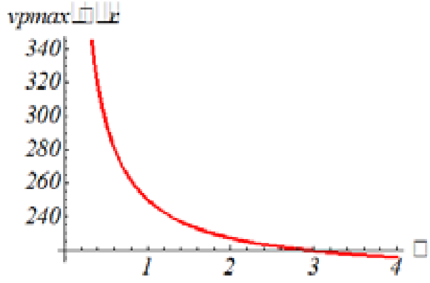

Fig.12 the piston velocity as a function of δ

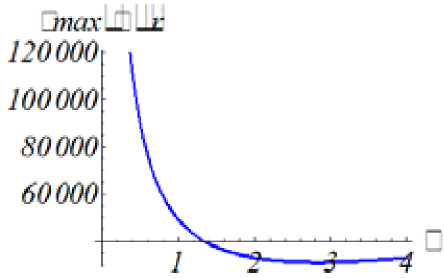

Fig.13 the piston acceleration as a function of δ

Conclusion:
The velocity and acceleration of the piston increases with a short connecting rod, thus more power produced by the engine, case sports cars. For a long connecting rod, the velocity decreases and also reduced friction at the cylinder but it will be a heavy engine.

4. Dynamic study
4.1 The connecting rod
Mechanical loads exerted on the connecting rod:

- action of the weight of the connecting rod
- action of the piston axis at the point A.
- action of the crankshaft at the point B.

No force is transmitted in the direction of the axis Oz.
No moment transmits to the connecting rod of the crankshaft crankpin.

A and B are pivot links.

Mechanical Actions torsor in B:

$$T_B\begin{cases}\overrightarrow{F_B}\\ \overrightarrow{M_B}\end{cases};\quad \overrightarrow{F_{B/R_0}}=\begin{cases}F_{Bx}\\F_{By}\\0\end{cases};\quad \overrightarrow{M_{B/R_0}}=\begin{cases}0\\0\\0\end{cases}$$

no effort along the axis $\overrightarrow{Bz}$.

Mechanical Actions torsor in A:

$$T_A\begin{cases}\overrightarrow{F_A}\\ \overrightarrow{M_A}\end{cases};\quad \overrightarrow{F_{A/R_0}}=\begin{cases}F_{Ax}\\F_{Ay}\\0\end{cases};\quad \overrightarrow{M_{A/R_0}}=\begin{cases}0\\0\\0\end{cases}$$

no effort along the axis $\overrightarrow{Az}$, the axis of the piston not transmit any moment of force to the connecting rod.

Differential Equations of motion of the connecting rod:

$$\begin{cases}m_{Rod}\overrightarrow{\gamma_G}=\sum\overrightarrow{F_{ext}}\\ \overrightarrow{\Gamma_G}=\sum\overrightarrow{M}(\overrightarrow{F_{ext}}/G)\end{cases}$$

Theorem the kinetic moment: $\overrightarrow{\Gamma_G}=\dfrac{d\overrightarrow{\sigma_G}}{dt}/_{R_0}$

$$\overrightarrow{\sigma_{G/R_0}}=\begin{bmatrix}\mu&0&0\\0&\eta&0\\0&0&\kappa\end{bmatrix}\cdot\begin{bmatrix}0\\0\\\dot{\varphi}\end{bmatrix}=\kappa.\dot{\varphi}\overrightarrow{e_{z_2}}$$

$$\overrightarrow{\Gamma_{G/R_0}}=\frac{d\overrightarrow{\sigma_G}}{dt}/R_0=\kappa.\ddot{\varphi}\overrightarrow{e_{z_2}}=\kappa.\ddot{\varphi}\overrightarrow{e_{z_0}}$$

Then we have:
Theorem the dynamic resultant

$$\begin{cases}m_{Rod}.\dfrac{L_0.\dot{\theta}^2.\sin\theta}{\delta}=F_{Ax}+F_{Bx}\\ m_{Rod}.r.\dot{\theta}.\left(\dot{\varphi}-\dot{\theta}-\dfrac{L_0}{L_1}.\dot{\varphi}\right).\cos\theta+m_{Rod}.r.\ddot{\varphi}.\left(1-\dfrac{L_0}{L_1}\right).\sin\theta=F_{Ax}+F_{Ay}\\ 0\end{cases}$$

theorem the kinetic moment:

$$\kappa.\ddot{\varphi}=(L_0-L_1).(F_{Bx}.\cos\varphi+F_{By}.\sin\varphi)+L_0.[F_{Ax}.\cos\varphi+F_{Ay}.\sin\varphi]$$

Conclusion :

$$m_{Rod}.\frac{L_0.\dot{\theta}^2.\sin\theta}{\delta}=F_{Ax}+F_{Bx}$$

$$m_{Rod}.r.\dot{\theta}.\left(\dot{\varphi}-\dot{\theta}-\frac{L_0}{L_1}.\dot{\varphi}\right).\cos\theta+m_{bielle}.r.\ddot{\varphi}.\left(1-\frac{L_0}{L_1}\right).\sin\theta=F_{Ax}+F_{Ay}$$

$$\kappa.\ddot{\varphi}=(L_0-L_1).(F_{Bx}.\cos\varphi+F_{By}.\sin\varphi)+L_0.[F_{Ax}.\cos\varphi+F_{Ay}.\sin\varphi]$$

We have three equations with four
Unknowns:

$$\begin{vmatrix}F_{Ax}\\F_{Bx}\\F_{Ay}\\F_{By}\end{vmatrix}$$

Therefore we study the movement of the piston.

4.2 The piston
The piston is a rigid or articulated moving in a combustion chamber of a shape adapted (a cylinder) for varying the volume of the chamber: this allows the conversion of pressure of the combustion gases into mechanical energy or inversely.

Dynamic Resultant:

$$m_p\overrightarrow{\gamma_{Gp}}=\sum\overrightarrow{F_{ext}}$$

$$\sum\overrightarrow{F_{ext}}=\begin{cases}F_{Hx}-F_{Ax}\\-F_{Ay}-F_{Qy}\\0\end{cases}$$

$$\begin{cases}F_{Hx}-F_{Ax}\\-F_{Ay}-F_{Qy}\\0\end{cases}=\begin{cases}0\\m_p.\left(r.\dot{\theta}(\dot{\varphi}-\dot{\theta}).\cos\theta+r.\ddot{\varphi}.\sin\theta\right)\\0\end{cases}\qquad(5)$$

Theorem the kinetic moment:

$$\frac{d\overrightarrow{\sigma_{Gp}}}{dt}/_{R_0}=\sum\overrightarrow{M}(\overrightarrow{F_{ext}})=\overrightarrow{M_{Gp}}(-\overrightarrow{F_A})+\overrightarrow{M}_{Gp}(\overrightarrow{F_H})+\overrightarrow{M_{G_p}}(\overrightarrow{F_Q})=\vec{0}$$

Then: $d_2.F_{Ax}-d_4.F_{Hx}=0$

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So all there are only five equations

$$\begin{cases} m_{Rod}.\dfrac{L_0}{\delta}.\dot{\theta}^2.\sin\theta = F_{Ax} + F_{Bx} & (1) \\ m_{Rod}.r.\dot{\theta}.\left[\dot{\varphi} - \dot{\theta} - \dfrac{L_0}{L_1}.\dot{\varphi}\right].\cos\theta + m_{Rod}.r.\ddot{\varphi}.\left(1 - \dfrac{L_0}{L_1}\right).\sin\theta = F_{Ay} + F_{By} - m_{Rod}.g & (2) \\ \kappa.\ddot{\varphi} = (L_0 - L_1).\left[F_{Bx}.\cos\varphi + F_{By}.\sin\varphi\right] + L_0.\left(F_{Ax}.\cos\varphi + F_{Ay}.\sin\varphi\right) & (3) \\ -F_{Ax} + F_{Hx} = 0 & (4) \\ m_{piston}.(r.\dot{\theta}.(\dot{\varphi} - \dot{\theta}).\cos\theta + r.\ddot{\varphi}.\sin\theta) = -F_{Ay} - F_{Qy} - m_p.g & (5) \end{cases}$$

$\begin{cases} F_{Ax} \\ F_{Ay} \\ F_{Bx} \\ F_{By} \\ F_{Hx} \end{cases}$ The unknowns are 5:

F_{Qy}: is a function of the gas pressure and the geometry of the piston:

$$F_{Qy} = S_{piston}.P(\theta) = \frac{\pi.D^2}{4}.P(\theta)$$

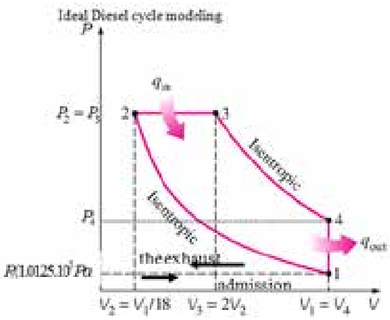
The resolution of the system dynamic equations can express all actions according to. F_{Qy}

F_{Qy} is a function of the gas pressure in the combustion chamber.

The pressure $P(\theta)$ is determined by a thermodynamic study.

5. Thermodynamic study.
The thermodynamic study of diesel cycle gives the gas pressure.

Diesel cycle:
Ideal Diesel cycle modeling



$$\begin{cases} V_t(\theta) = V_m + \dfrac{z.\pi.D^2}{4} \\ z = L_1 + r.(1 - \cos\theta) - \sqrt{L_1{}^2 - r^2.\sin^2\theta} \end{cases}$$

The mixed cycle
In practice, the combustion in the engine compression ignition does not proceed as described by Diesel at constant pressure. The heat is partly at constant volume and partly at constant pressure mixed cycle.

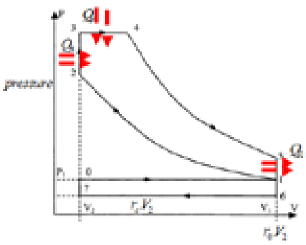


Fig .14 Mixed cycle

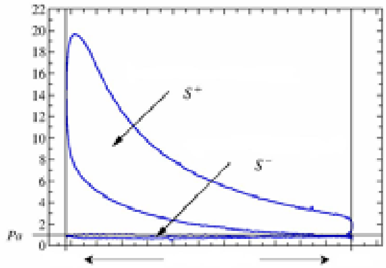


Fig.15 Real Diesel cycle

$$\begin{cases} \kappa = \dfrac{P_3}{P_2} \\ r_c = \dfrac{V_4}{V_2} = \dfrac{V4}{V_3} \end{cases}$$

Each phase of the cycle lasts q = 180 ° = p rad. q is the angle of the crankshaft crank pin.

An engine cycle has four phases:- Admission
- Compression
- Expansion
- AndExhaustwhich is: 720 °

The combustion step is activated at the end of each compression step and occurs between the end of compression and the start of expansion.

Internal combustion Engine: the four phases of the engine cycle and pressure.

- Intake: ; $P(\theta) = 1{,}01325.10^5\,Pa \quad 0 \le \theta \le \pi$
- Compression: $P(\theta) = \dfrac{P_1.V_1^{\gamma}}{\left(\left[V_m + r.(1-\cos\theta) + L_1.\left(1 - \sqrt{1 - \dfrac{r^2.\sin^2\theta}{L_1{}^2}}\right)\right].\dfrac{\pi.D^2}{4}\right)^{\gamma}}$
  $\pi \le \theta \le 2.\pi$
- Combustion : $P(\theta) = \dfrac{P_1.V_1^{\gamma}}{\left(\left[V_m + r.(1-\cos\theta) + L_1.\left(1 - \sqrt{1 - \dfrac{r^2.\sin^2\theta}{L_1{}^2}}\right)\right].\dfrac{\pi.D^2}{4}\right)^{\gamma}}$
  $2.\pi \le \theta \le 3.\pi$
- Exhaust: ; $P(\theta) = 1{,}01325.10^5\,Pa \; 3.\pi \le \theta \le 4.\pi$

6. Numerical study

$$\begin{cases} P_1 = 1.013.10^5\,Pa \\ V_1 = 1.917.10^{-3}\,m^3 \\ r_0 = \dfrac{V_t}{V_m} = 1 + \dfrac{V_d}{V_m} \\ V_t = V_d + V_m \\ V_d(PMH - PMB) = V_h = 2.r.\dfrac{\pi.D^2}{4} \\ V_m = \dfrac{V_h}{r_0 - 1} \end{cases}$$ z

$$\begin{cases} D = 75{,}8mm \\ L_1 = 15cm \\ r = 38.25mm \\ L(PMH - PMB) = 2.r = 76.5mm \\ \gamma = 1.4 \\ r_0 = 18 \end{cases}$$

Using the computer code Mathematica, we draw the curve of

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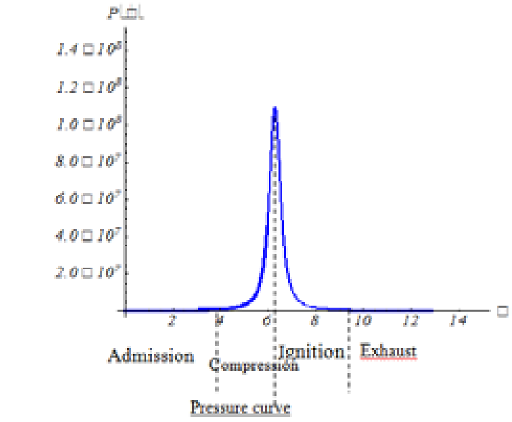
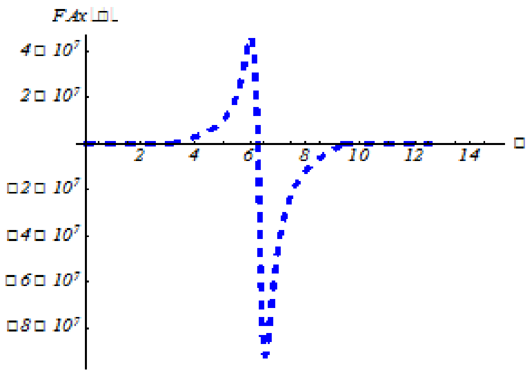
pressure and the curves representing the loads on the connecting rod: at the small end and the big end:

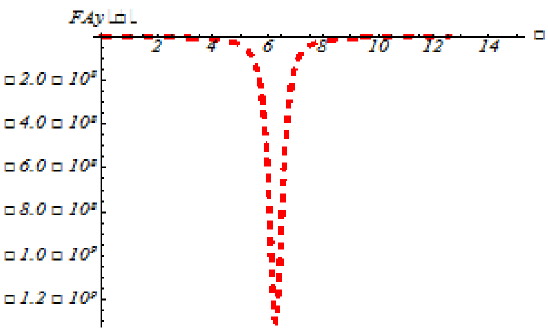


Pressure curve

* Action of the piston the region of contact A:

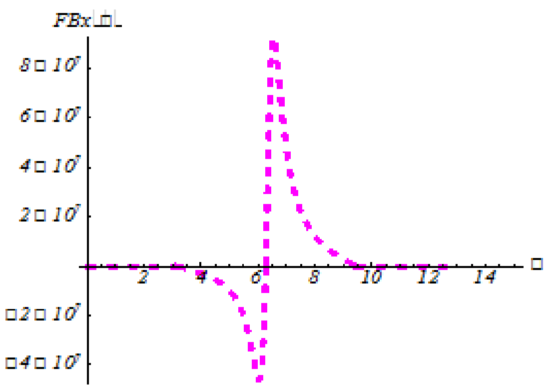


The component following ox_0

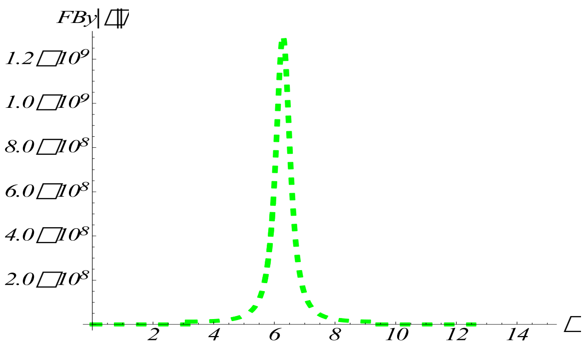


The component following oy_0

* Action of the piston the region of contact B:



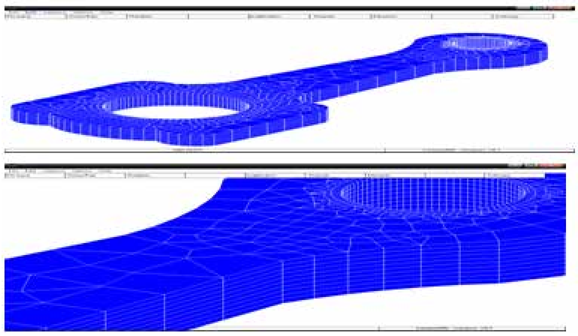
The component following ox0



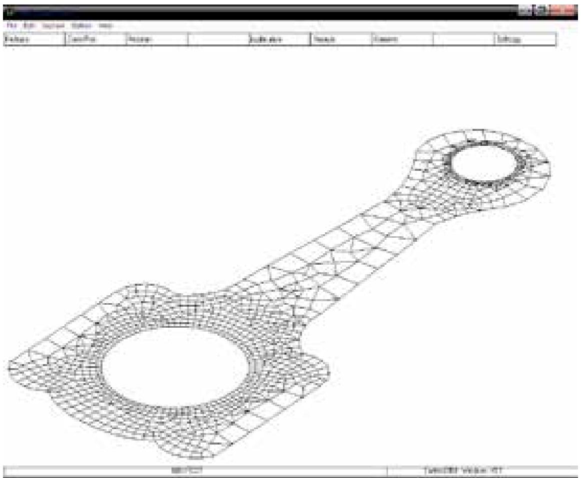
The component following oy_0

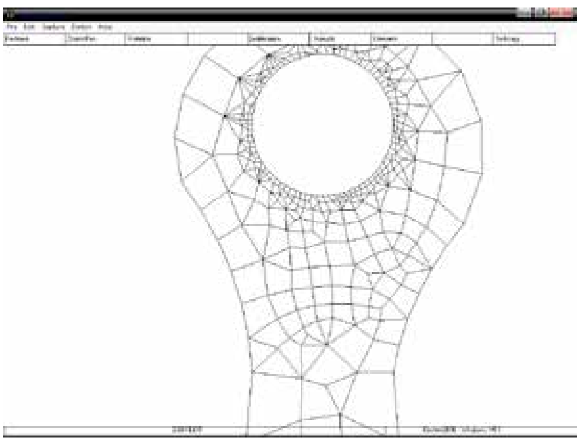
Using the computer code Cast3M and the finite element method that's it introduced, and under the action of compression loads, we extract the stresses, strains and the corresponding displacements.

Meshing



Three dimensional meshing





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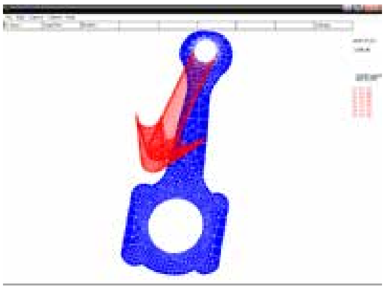
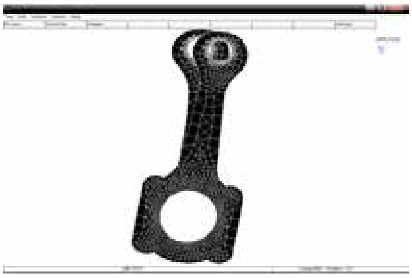
Two dimensional meshing

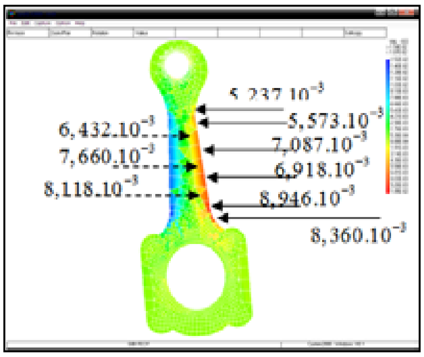


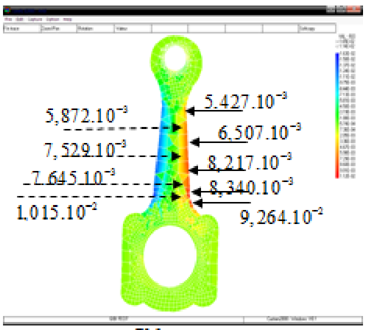
Force vector representing the compressive loading



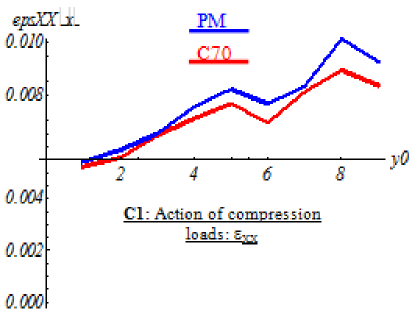
Superposition of the free state and the deformed state of the connecting rod

Deformation field for forged steel connecting rod: C70 and Powder metal: PM

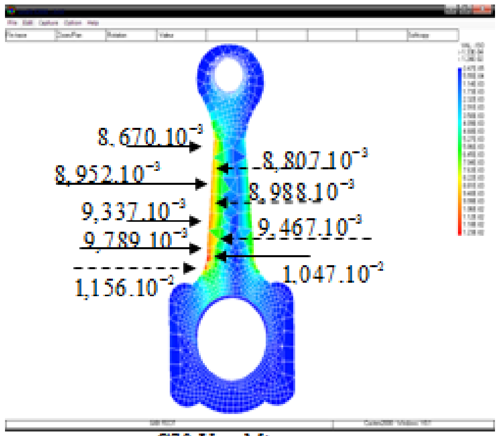




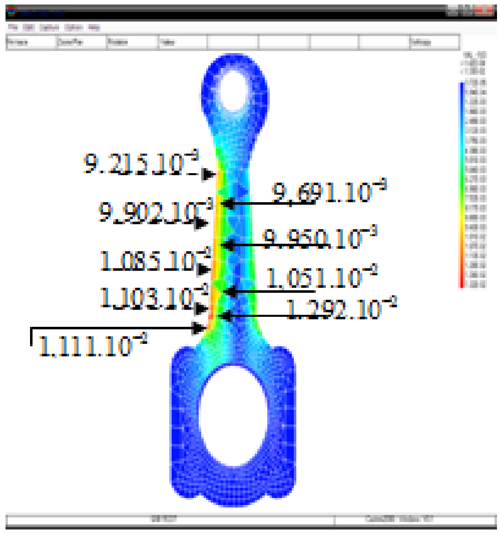
ε_{XX} PM



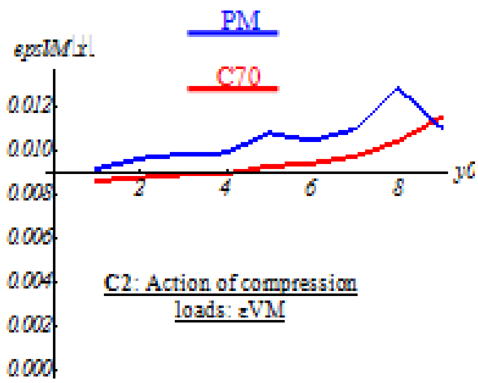
C1: Action of compression loads: ε_{XX}



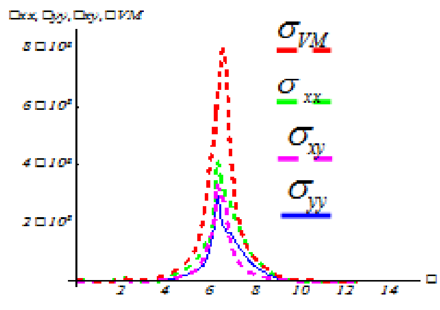
ε_{VM} C70 Von Mises



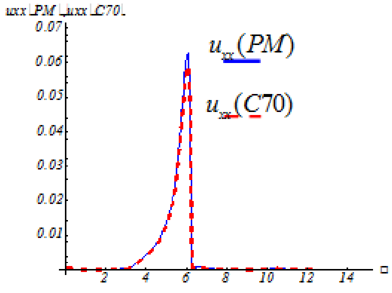
ε_{VM} PM Von Mises



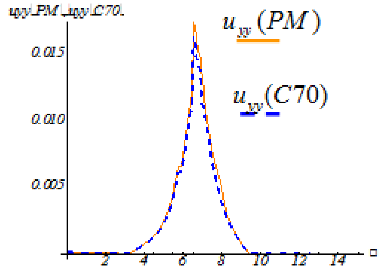
C2: Action of compression loads: εVM



The stresses

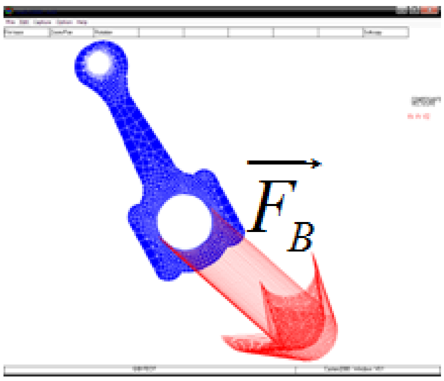


displacement along the ox

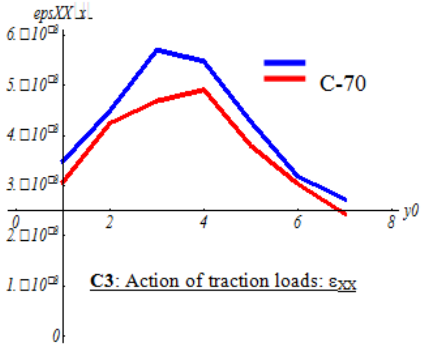


Displacement along the oy

Action of traction loads:



Force vector representing the traction loads



Conclusion

From the above results it can be concluded that the steel and special steel C70 unalloyed or low-alloy (average carbon content C: 0.65/0.90%, Heat Treatment very tight) is by far very performance compared to the metal powder.

- Compressive strength of the order of 19% [2]
- Tensile strength of the order of 8% [2]
- Hardness between 210 HB and 360 HB.

With the invention of steel C70 "C~0.65/ 0.90%, Si~0.25% , M n ~ 0.78%, Ni ~0.08% , Cr ~0.05%, Mo ~0.01% , Cu ~0.3%, S ~0.07% S , P~ 0.045%, 0 Al~.002%, N ~ 0012%,the balance being iron and impurities resulting from the development " we can reliably produce connecting rods cleavable structures types ferritic- pearlitic, formed of two elements obtained by fragile rupture, easily machined at low speed and high speed of cut and better performing than that of originally PM

Perspectives: Studies thermal and fluid "lubrication".

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