DESIGN AND OPTIMIZATION OF CONNECTING ROD FOR 97 CC FOUR STROKE GASOLINE ENGINE

THIẾT KẾ VÀ TỐI ƯU THANH TRUYỀN CHO ĐỘNG CƠ BỐN THÌ 97 CC

Nhiem Tran Quoc[1], **Long Xuan Le**[2]
[1]Department of Machanical Engineering, University of Food Industry, Ho Chi Minh City
[2]Department of Machanical Engineering, Thu Duc College of Technology, Ho Chi Minh City

ABSTRACT

The connecting rod is one of the important parts in an internal combustion engine, it connects the piston and the crankshaft, converting the reciprocating motion of the piston into rotation of the crankshaft. The main objective of this paper is to design connecting rods based on comparison of 3 different materials including C-70 steel, FS steel, PM steel, then select the best material for design, using software. connecting rod design is Inventor professional 2020, and finally optimizing the connecting rod for 4-stroke 97 cc gasoline engine, using Ansys 18.2 software to analyze and optimize, with the aim of increasing durability, longevity, volume optimization.

Keywords: *Numerical analysis; Connecting rod; Multiple-objective optimization; Internal combustion engine.*

TÓM TẮT

Thanh truyền là một trong các chi tiết quan trọng trong động cơ đốt trong, nó liên kết pittong và trục khuỷu, biến chuyển động tịnh tiến của pittong thành chuyển động quay của trục khuỷu. Mục tiêu chính của bài báo này là thiết kế thanh truyền dựa trên so sánh 3 loại vật liệu khác nhau gồm thép C-70, thép FS, thép PM, sau đó lựa chọn vật liệu tốt nhất để thiết kế, phần mềm sử dụng thiết kế thanh truyền là Inventor professional 2020, cuối cùng là tối ưu hóa thanh truyền cho động cơ xăng 4 kỳ 97 phân khối, dùng phần mềm Ansys 18.2 để phân tích và tối ưu, với mục đích tăng độ bền, tuổi thọ, tối ưu khối lượng.

Từ khóa: *Phân tích số; Thanh truyền; Tối ưu hóa đa mục tiêu; Động cơ đốt trong.*

1. INTRODUCTION

The connecting rod is also known as the boundary arm. This is a connection between the piston and the machine core. The connecting rod acts as an intermediary to transmit the force from one part to another and vice versa. The connecting rod is composed of the main parts: the connecting rod body, the big end, the small end, and the big end bushing. The connecting rod performs the task of transmitting force from the crankshaft to the piston to compress the air in the combustion chamber. At the same time, the connecting rod performs the task of transmitting force from the piston generated by the expanding combustible gas to the crankshaft so that the shaft can rotate. Thanks to the transmission of force of the connecting rod and the handwheel, the rectilinear travel of the piston creates a circular movement of the engine core, and remember that, the automobile engine system operates more stably and smoothly. During operation, the connecting rod is subjected to compressive, flexural, and sometimes even tensile stress. The shape of the connecting rod structure creates the greatest concentrated stress at the outer surface of the transition between the body and the end of the connecting rod. Working conditions of connecting rods depend on many factors such as: piston top pressure, material hardness, selection of materials, assembly technology...

Therefore, determining the stress value, the position of the stress, minimizing the mass of the connecting rod is very important, as a basis for increasing durability, improving the service life, reliability, and ensuring the safety of the engine.

2. MATERIAL AND METHODS

2.1. Selection of Materials and Properties

- Different types of materials are used to make connecting rods, such materials include alloy steel C-70 (Alloy steel), FS steel (forged steel), PM steel (Powder metal).

Table 1. Material properties of selected materials for connecting rods:

Serial No.	Parameters	C-70 Alloy steel	FS Forged steel	PM Powder metal
01	Yield strength (MPa)	574	700	588
02	Ultimate strength (MPa)	966	938	866
03	Modulus of elasticity (GPa)	212	201	199
04	Density (g/cm^3)	7700kg/m^3	7806 kg/m^3	7850 kg/m^3
05	Poisons ratio	0,3	0,3	0,29
06	Strength coefficient, K (MPa)	1763	1400	1379
07	Fatigue strength coefficient, σ_f (MPa)	1303	1188	1493
08	Fatigue Strength Exponent, b	-0.0928	-0.0711	-0.1032
09	Fatigue Ductility Coefficient, $\varepsilon_{f'}$	0.5646	0.3576	0.1978
10	Fatigue Ductility Exponent, c	-0.5861	-0.5663	-0.5304
11	Cyclic Strength Coefficient, K' (MPa)	1739	1397	2005
12	Cyclic Strain Hardening Exponent, n'	0.1919	0.1308	0.1917

2.2. Analytical calculation for maximum gas Pressure, maximum gas Force, Inertia force of reciprocating parts, maximum force acting on the connecting rod

- Engine specifications:
+ Engine type air cooled 4-stroke, 97 cc.
+ Bore × Stroke (mm): 50x49,5.
+ Cylinder capacity: 97,1 cc.
+ Maximum Power: 4,41 Kw/7000 rpm.
+ Maximum Torque: 6,03 Nm/5000 rpm.
+ Compression Ratio: 9,0:1.

Gas pressure acting on piston.

$$B.P = \frac{2\pi n M}{60} = \frac{2.3{,}14.5000.6{,}03}{60} = 3155{,}7\ W \quad (a)$$

$$\eta = \frac{BP}{IP} \rightarrow BP = 0{,}8.IP \quad (b)$$

$$IP = p.\frac{\pi}{4}.D^2.L_{pt}.n$$

$$\rightarrow IP = p.\frac{\pi}{4}.(0{,}05)^2.(0{,}0495).\frac{5000}{60} \approx 0{,}008.p \quad (c)$$

From (a), (b), (c) deduce: 3155,7 =0,8.0.008.p.
→ p=49,3.10 4 N/m² = 0,493 MPa
with p_{max} = (9÷10).p = (9÷10).0,493 = 4,43÷4,93 MPa,
select p_{max} =4,93 MPa.
+ BP: Brake Power,W.
+ IP: Indicated Power,W.
+ L_{pt}: Stroke of piston, m.
+ p: Gas pressure acting on piston, N/mm².
+ n: Engine revolution (vòng/phút).
+ D: Diameter of piston, m.
+ η: Efficiency.
+ M: Torque of engine, N.m.
+ FN: Horizontal force acting on cylinder wall.

Inertia force of reciprocating parts..

$$F_I = m_R R\omega^2(\cos\varphi + \lambda\cos 2\varphi) = mR.J$$

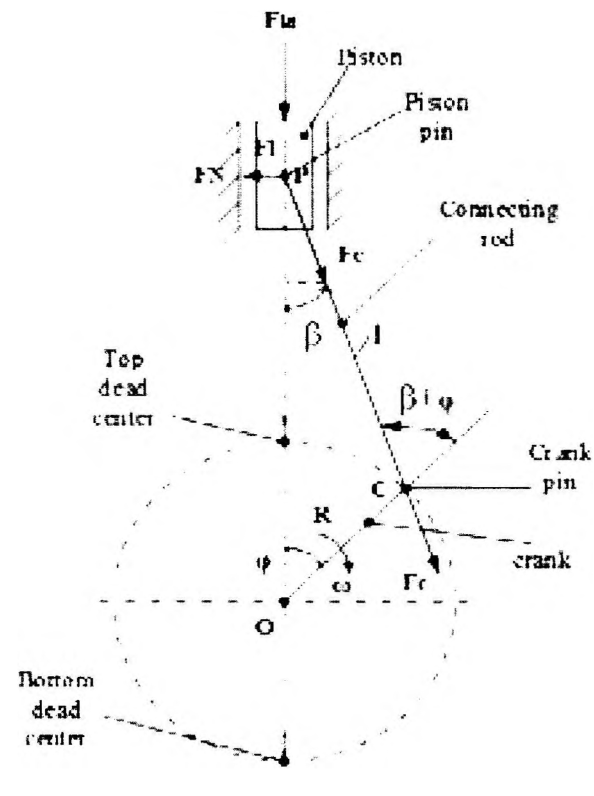

Figure 1. Forces acting on the connecting rod

(mR: Mass of reciprocating parts (Mass of piston, rings, gudgeon pin + $\frac{1}{3}$ rd mass of connecting rod).
+ $m_{piston} \approx 0{,}153$ Kg.
+ $m_{gudgeon}$ pin ≈ 0,016 Kg.
+ $m_{rings} \approx 0{,}021$ Kg.
+ $m_{connecting\ rod} \approx 0{,}115$ Kg.
+ ω: Angular speed of crank.
+ β: Angle of inclination of the connecting rod with the line of stroke.
+ J: acceleration of reciprocating parts.
+ φ: Angle of inclination of the crank from top dead center.
+ R: Radius of crank.
+ l: length of connecting rod.

+ λ = Ratio of length of connecting rod to radius of crank, $\lambda = \frac{R}{l}$

- F_{Imax} =((0,153+0,016+0,021+0,115.(1/3)).

$$49.5$$

$$\frac{2}{1000}.73267^2(1+0.25) = 0.23.166074 = 3792N$$

(where $\omega = \frac{n.\pi}{30} = \frac{7000.3.14}{30} = 73267$

(rad/s); $\lambda = \frac{R}{l} = \frac{24,75}{99} = 0,25$; φ= 0°)

Maximum gas force acting on the piston

$$-p_{max} = \frac{F_{ktmax}}{A} \rightarrow F_{ktmax} = p_{kt}.A = 49.5.\pi.\frac{D^2}{4} = 49.5.\pi.\frac{50^2}{4} = 9675.1N$$

with:
+p_{max}: Maximum gas pressure acting on piston, N/mm².
+A: Cross-section area of piston, mm².
+F_{ktmax}: Maximum gas force acting on piston, N.
Maximum force acting on the connecting rod
- $F_{Cmax} = F_{ktmax}/\cos\beta$.

$$\Leftrightarrow F_{Cmax} = \frac{F_{ktmax}}{\sqrt{1-\sin^2\beta}} = \frac{F_{ktmax}}{\sqrt{1-\lambda^2\sin^2\varphi}} = \frac{F_{ktmax}}{\sqrt{1-\lambda^2}} =$$

$$\frac{9675.1}{\sqrt{1-0.25^2}} = \frac{9675.1}{\sqrt{0.9375}} = \frac{9675.1}{0.9682} \approx 9993 N$$

(Force acting on the connecting rod is maximum when φ = 90°).

2.3. Modeling of Connecting Rod

- The connecting rod was designed and drew on Inventor professional 2020, design reference in documentation.

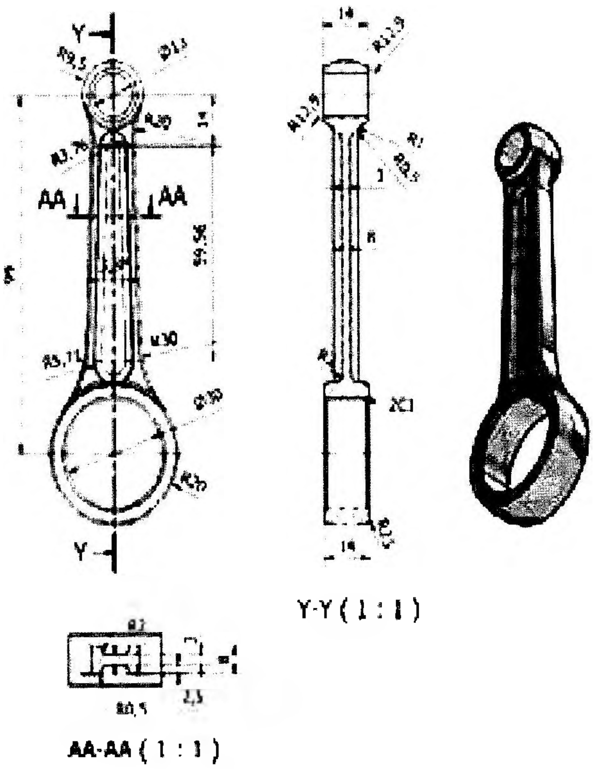

Figure 2. Dimensions of connecting rod

2.4. Analysis equivalent stress, Fatigue life, safe factor

FEA for Connecting Rod Without Thermal Effects For C-70:

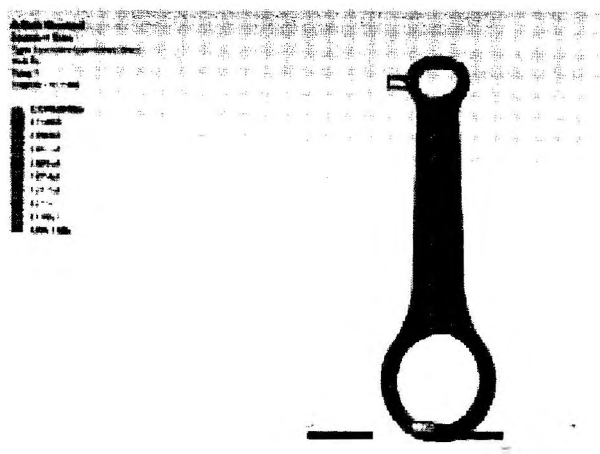

Figure 3: Equivalent stress

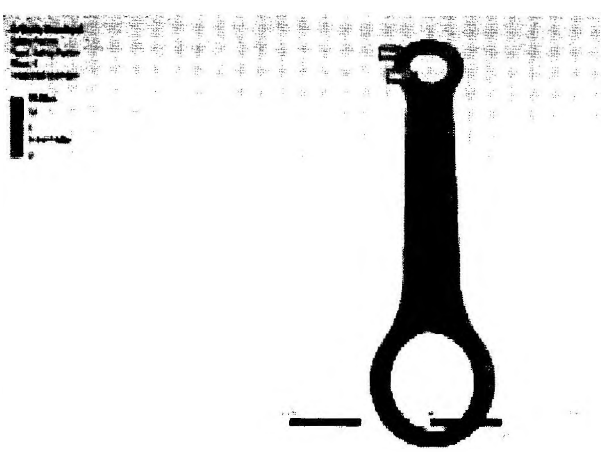

Figure 4: Safety factor

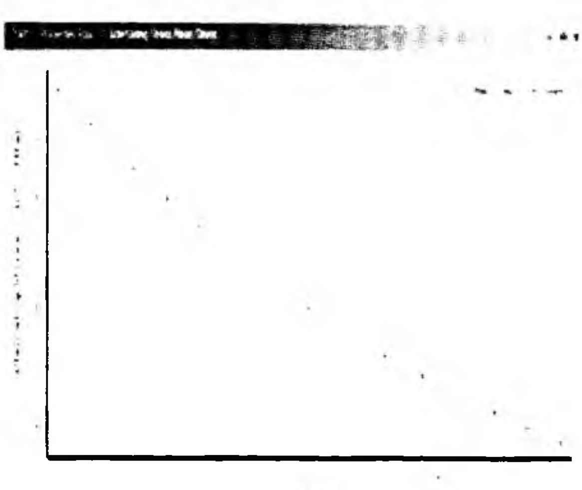

Figure 5: Fatigue curve of C-70

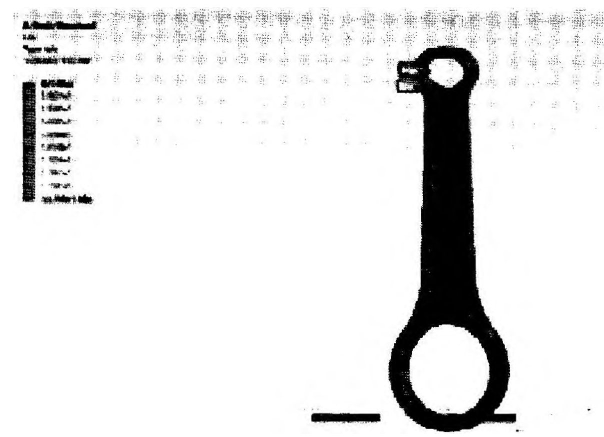

Figure 6: Fatigue life according to Goodman For FS

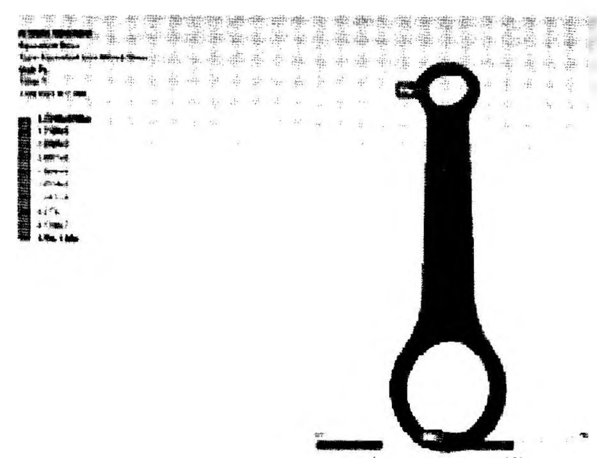

Figure 7: Equivalent stress

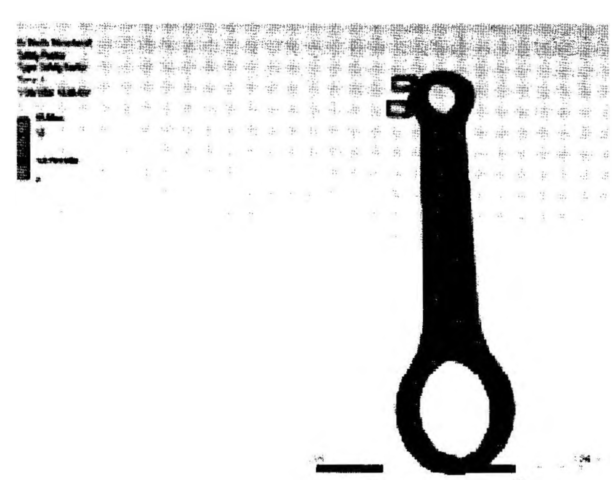

Figure 8: Safety factor

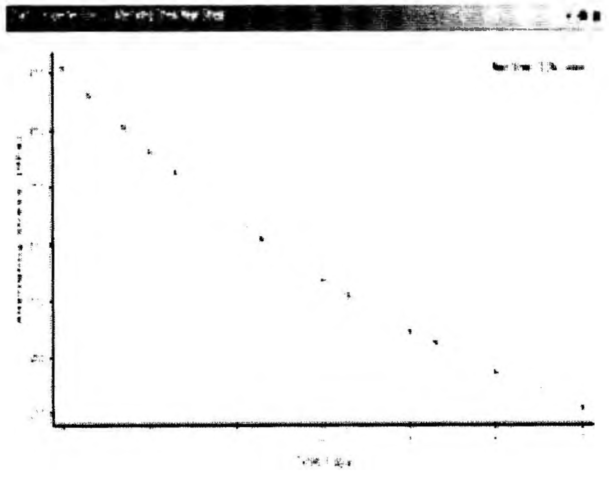

Figure 9: Fatigue curve of FS

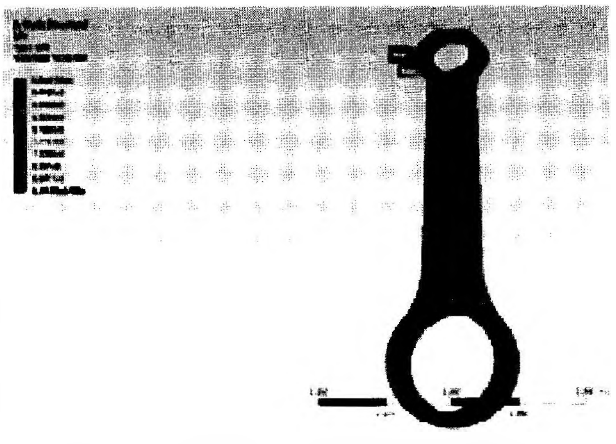

Figure 10: Fatigue life according to Goodman For PM:

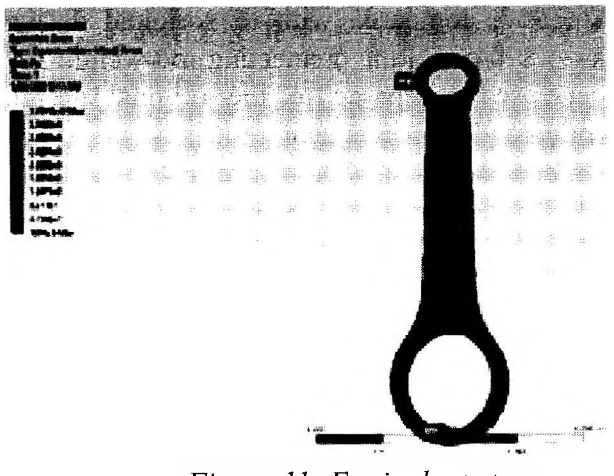

Figure 11: Equivalent stress

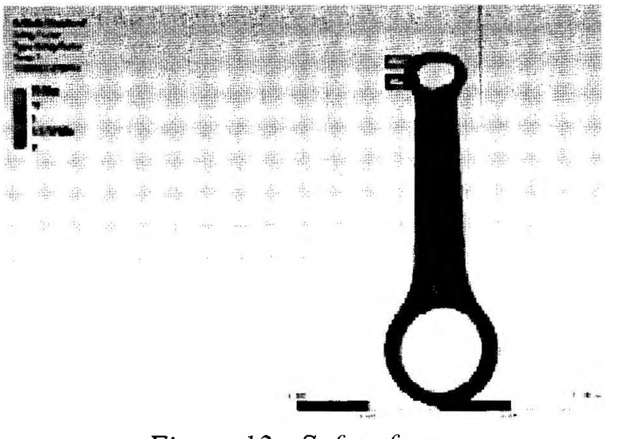

Figure 12: Safety factor

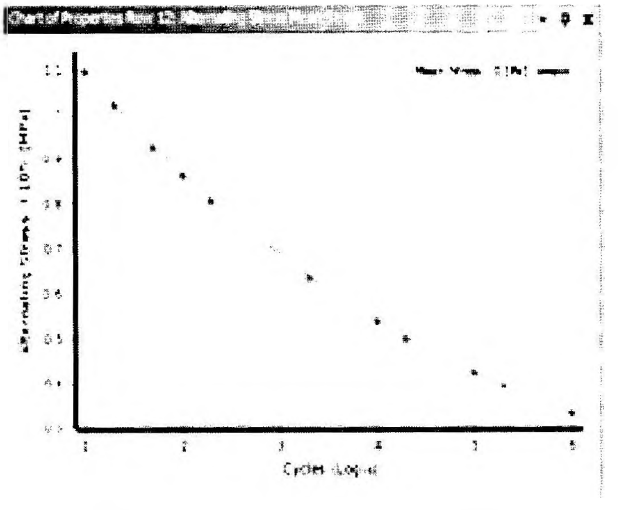

Figure 13: Fatigue curve of PM

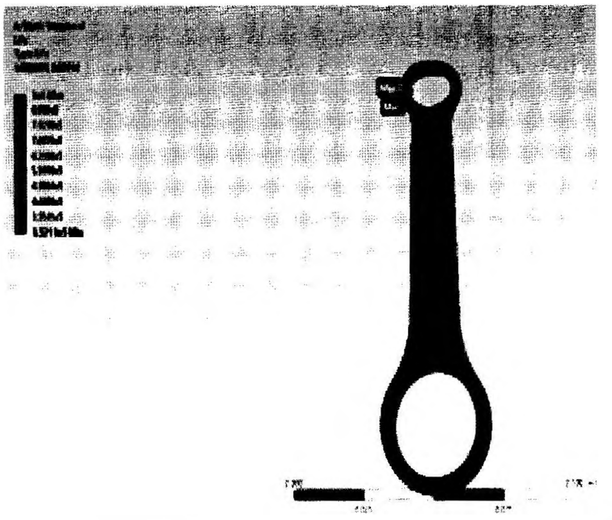

Figure 14: Fatigue life according to Goodman ☞

Table 2. Summary on results of the FEA without thermal effects:

Serial No	Types	C-70 (alloy steel)		FS (Forged steel)		PM (Powder metal)	
		Max	**Min**	**Max**	**Min**	**Max**	**Min**
1	Equivalent stress (MPa)	372,46	1,2965e-3	372,46	1,2965e-3	372,46	1,2965e-3
2	Total deformation (mm)	7,762e-2	0	8,1868e-2	0	8,2655e-2	0
3	Equivalent elastic strain(mm/mm)	1,7573e-3	6,4586e-9	1,8535e-3	6,8121e-9	1,8757e-3	6,9497e-9
4	Safety factor	15	1,5411	15	1,8794	15	1,5757
5	Fatigue Life, N	4e5	3,6799e5	9.9e6	6,3178e6	1e6	3,5211e5

- The connecting rod is designed by 3 types of steel C70, FS, PM, showing that the safety factor k when the design of FS steel (k=1.8794) is the highest compared to that of C70 steel (k=1.5411), steel PM (k=1.5757).

- And the service life of connecting rod when designed by FS steel is also the highest (N=9,9e6 cycle) compared to C70 steel (N=4e5 cycle) and PM steel (N=1e6 cycle).

For the above reason, we choose FS steel as the material when designing the connecting rod for the 4-stroke 97cc gasoline engine.

3. CONCLUSION

The results of the project are achieved based on the theoretical calculation of the kinetic and dynamical equations. The experimental planning method, the finite element method, combined with the simulation support software Ansys 18.2 and Inventor.

- After designing and optimizing, we see that the connecting rod made of FS material after optimization has a minimum safety factor k=3,058, compared with the original design k= 1.8794; and the connecting rod weight has decreased compared to the original design (original design connecting rod mass m = 0.115 kg, connecting rod weight after optimization m = 0.114 kg).

- With this result, the safety factor of connecting rod after optimization has increased 1.62 times compared to the original design and increased the life of the connecting rod.

- If comparing the mass of the connecting rod after optimization with the actual weight of the connecting rod in an engine of the same displacement, the mass of the connecting rod is reduced by about 10% compared to the actual mass, contributing to reduce the impact of inertia force causing pulling, causing rod bending, thereby contributing to increasing the life of the connecting rod. ❖

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