Design, analysis and optimization of gudgeon pin

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***Abstract*—The gudgeon pin is an essential component in internal combustion engines, connecting the piston to the connecting rod and transmitting combustion forces. It operates under severe conditions such as high cyclic loading, temperature fluctuations, and frictional wear. This project focuses on the design, analysis, and optimization of a gudgeon pin to improve its strength, durability, and weight efficiency.**

Initially, the gudgeon pin is designed using standard mechanical design principles. Analytical calculations are performed to determine stresses and dimensions. A 3D model is then developed and analyzed using Finite Element Analysis (FEA) to study stress distribution and deformation under working conditions. Based on the results, design modifications are made by varying geometric parameters and material properties.

The optimized design shows reduced weight and improved stress handling capability compared to the initial design. The project concludes that proper design optimization of the gudgeon pin can enhance engine performance, increase component life, and reduce material usage.

***Index Terms*—Gudgeon Pin, Piston Pin, Finite Element Analysis (FEA), Design Optimization, Stress Analysis, Fatigue Life, Internal Combustion Engine, Mechanical Design, Weight Reduction, Structural Analysis.**

I. INTRODUCTION

The gudgeon pin, commonly referred to as the piston pin, is an essential component in internal combustion engines, facilitating the connection between the piston and the connecting rod while transmitting dynamic combustion loads. It operates under severe conditions involving high cyclic stresses, temperature variations, and friction, making its design critical for engine reliability and performance.

With increasing emphasis on fuel efficiency and emission reduction, modern engineering practices prioritize lightweight and high-strength components. The gudgeon pin, being part of the reciprocating mass, directly influences engine dynamics and efficiency. Therefore, optimizing its design to reduce weight while maintaining structural integrity is of significant importance.

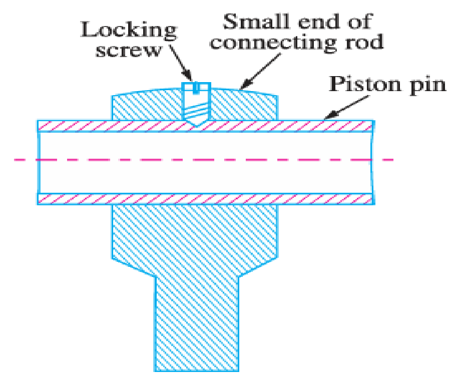

Fig. a. Piston pin secured to the small end of the connecting rod.

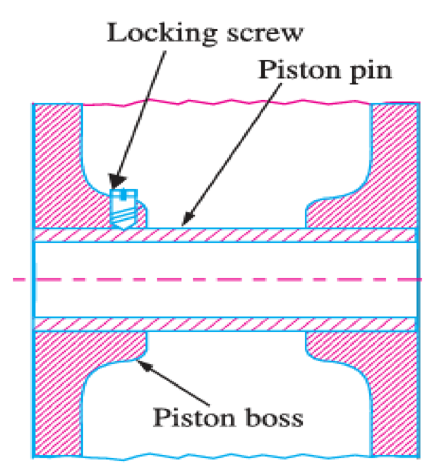

Fig. b. Piston pin secured at the boss of the piston
Fig.a and b. Semi floating type piston pin

Conventional design approaches rely on analytical methods, which may not fully capture complex stress distributions. The adoption of Finite Element Analysis (FEA) enables accurate evaluation of stress, strain, and deformation under realistic loading conditions. This facilitates the identification of critical regions and supports design improvements.

This study presents the design analysis and optimization of a gudgeon pin using a combination of analytical methods and FEA. The objective is to minimize weight and improve fatigue performance while ensuring safe operation under engine conditions. The results contribute to the development of efficient and reliable engine components through simulation-driven design optimization.

II. LITERATURE REVIEW

A gudgeon pin links the piston to the connecting rod via rotation; it endures intense thermal stresses throughout an engine's operational cycle. The design of machine elements was carried out by B. Bhandari [1].

K. Optimizing Gudgeon Pins using FEA Analysis: A Study by R. Suchendra and K. J. [2], focusing on reducing stress concentrations in designs; also examined by Chetan B. Deshmukh [3]. In June of 2023, In April 2019, Miss Kranti Kharade, Miss Rucha Kamble, Miss Deepali Veer, Miss Nandini Maher along with Professor R. G. Maske designed and manufactured gudgeons pins for Yanxia Wang and Hui Gao's study which revealed that due to fatigue failures caused by different mechanical stresses, an optimized design was proposed for both pistons' pins and bosses through FEA static analyses. Vaishali R. Nimbarte [6] conducted studies involving stress evaluation, temperature assessment, as well as heat-affected mechanics research. The variable employed in our study pertains to operational gas pressure, ambient temperatures, and characteristics of pistons. The intricate IC engine's crankshaft is its critical component; thus, ensuring it operates efficiently ensures optimal vehicular performance. Dilip Kumar[7] mentions that he has researched that engine pistons constitute an intricate part within various industrial sectors including automobiles. An automobile's power comes primarily from its engine, which is often referred to as the "heart" of the vehicle; within this core component lies what many consider to be the most crucial element: the piston. Despite numerous investigations, an enormous quantity of malfunctioning cylinders remains unaddressed.

III. PROBLEM STATEMENT

The challenge is to design a gudgeon pin that can withstand these operating conditions while minimizing weight and material cost. Therefore, there is a need to analyze the existing design and optimize its geometry and material to achieve improved strength, durability, and performance.

IV. METHODOLOGY

The methodology adopted for this project is as follows:

Step	Methodology
1	Literature Survey
2	Design Calculations
3	3D Modeling
4	Finite Element Analysis (FEA)
5	Optimization
6	Result Comparison

V. MATERIAL SELECTION

The selection of material for the gudgeon pin is critical to ensure high strength, wear resistance, and long fatigue life under severe operating conditions. In this study, two commonly used high-strength steels are considered for comparison.

I. Case Hardened Steel

Case hardened steel is widely used for gudgeon pins due to its hard outer surface and tough core. The hardened surface provides excellent wear resistance and withstands high contact stresses at the piston and connecting rod interface. The ductile core helps absorb shock loads, reducing the risk of brittle failure.

II. 34CrNiMo6 Steel

34CrNiMo6 is a through-hardened alloy steel known for its high tensile strength (850–1550 MPa) and good toughness. It offers uniform strength throughout the material and is suitable for components subjected to bending and torsional loads.

Material properties		
Property	34CrNiMo6	Case Hardened Steel (e.g., EN36)
Hardening Method	Through-hardened (Uniform)	Surface-hardened (Case + Core)
Surface Hardness	248 – 302 HB (Condition T)	58 – 64 HRC (After Carburizing)
Core Toughness	Very High	Extremely High (Ductile Core)
Yield Strength	650 – 680 MPa	380 – 450 MPa (Core Value)
Tensile Strength	850 – 1000 MPa	700 – 1000 MPa
Wear Resistance	Moderate	GOOD (Superior for pins/gears)
Best Application	High-tensile shafts/bolts	Gudgeon pins, gears, camshafts

Chemical properties		
Element	34CrNiMo6	Case Hardened (EN36) (%)
Carbon (C)	0.36 – 0.44	0.12 – 0.18
Nickel (Ni)	1.30 – 1.70	3.00 – 3.75
Chromium (Cr)	1.00 – 1.40	0.60 – 1.10
Molybdenum (Mo)	0.20 – 0.35	N/A
Manganese (Mn)	0.45 – 0.70	0.30 – 0.60
Silicon (Si)	0.10 – 0.35	0.10 – 0.35
Sulphur (S)	0.040	0.040
Phosphorus (P)	0.035	0.040

VI. CALCULATIONS

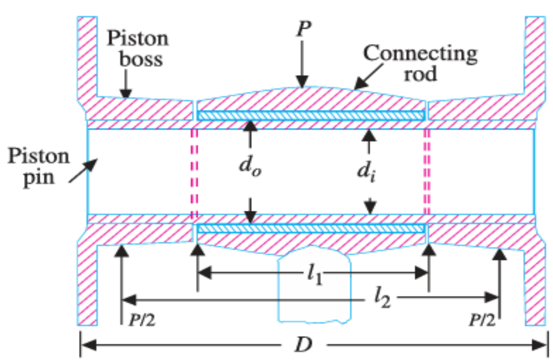

Fig.c. Piston pin

The design of the piston and gudgeon pin must satisfy several functional and structural requirements to ensure efficient engine performance and durability. The piston must possess adequate strength to withstand high mechanical loads and thermal stresses generated during combustion. It should maintain sufficient tensile and fatigue strength under cyclic loading conditions.

Weight is a critical factor in piston design. Excessive mass increases inertial forces, leading to higher stresses in the connecting rod and crankshaft mechanism. Therefore, the piston and pin should be designed to be lightweight while maintaining structural integrity, thereby improving overall engine efficiency and reducing energy consumption.

The piston skirt must provide an adequate bearing surface to ensure proper guidance within the cylinder and to minimize wear and friction during operation.

Additionally, the gudgeon pin and piston assembly should allow smooth reciprocating motion of the crankshaft mechanism under high-speed conditions. Proper balancing and alignment are essential to minimize piston knock, reduce engine vibrations, and ensure stable operation.

Design Parameter:

Heat flows through the piston head (H)

Piston head thickness (tH)

Radial thickness of the ring (t1)

Axial thickness of the ring (t2)

Width of the top land (b1)

Width of other ring lands (b2)

Design calculations of gudgeon pin

Heat flows through the piston head (H):

We know that heat flowing to piston head

H=C x HCV x M x BP [1]

The constant signifies the fraction of thermal energy transferred to the engine cylinder that is utilized through reciprocating motion of the crankshaft.

Which is normally taken as C=0. 05

High Calorific Value (HCV)=42 x 103Kj/Kg

Fuel Consumption (M)=41. 7 x 10-6 Kg/BP/Sec

Break Power (BP)=27. 56KW

The value of H is zero. The product of five multiplied by forty-two, then by ten cubed, followed by four-one is calculated as follows: 5 42 10^3 41 = 8679000. Seven times ten to the power of negative six multiplied by twenty-seven equals two point seven three four five nine eight seven zero one. The power output is 56 kilowatts.

H=2. 41KW

H=2410W

Thickness of piston head (t_H):

$t_H = H/12.56K(Te - Tc)$ [1]

For cast iron (k)=46.6W/m^{0}c.
t_H=0.1871m
t_H=18mm.
Radial thickness of the ring (t_1) :
Let us assume there are 4 rings out of which 3 are compression rings and one is an oil ring.
We know that radial thickness of piston ring
t_1=D x √3Pw/σt [1]
Here assume D=68.5mm,
P_W=0.035N/mm^2
6_t=90Mpa.
t_1=2.33mm.
Axial thickness of the ring (t_2):
t_2= D/10nt [1]
t_2=1.7125mm
Width of the top land (b_1):
b_1=t_H or 1.2 t_H
b_1=18 or 21.6mm
Width of other ring lands (b_2):
b_2=0.75t_2 or t_2
b_2 = 1.5 or 1.71mm
D_O= Outside dia. of pin in mm.
The parameter L1 represents the diameter of the cylindrical component's smallest section measured in millimeters. The value of L1 equals zero. The value of 45 multiplied by D equals 30. 825 millimeters.
The bearing pressure on the smaller end of CR bushing equals 25 Newtons per square millimeter, which represents its specified limit.Load on pin due to bearing pressure=
=P_{b1} x D_O x L_1
=25 x D_O x 0.45 x 68.5
=770.62D_O mm.
We know the max. load on the piston due to gas pressure or max. gas load
P = $^{\Pi}$ /4 x D^2 x p [1]

P = $^{\Pi}$ /4 x 68.5^2 x 2.5 N/mm^2
P = 9213.21 N
From above we can find that
770.62 D_O = 9213.21
D_O = 11.95mm
D_O = 12mm
D_i = 0.6 x D_O
D_i = 7.17mm
Max. Bending moment at centre of pin.
M = PD/8 [1]
M = 78888.11N.mm
M = 78.88 x 10^3 N.mm

We also know that max. Bending moment.
M = Π/32*{Do^4-Di^4/Do}* σb [1]
6_b = 532.94 N/mm^2
As above value is very high considering permissible bending stress 170N/mm^2 we will get
Do = 17.8mm. Taking Do=20mm and Di=12mm
Bending stress by using above formula 115.39N/mm^2
Shear stress developed in the pin is given by formula

T= P/2{Π/4(Do^2-Di^2)} [1]

τ = 22.91N/mm^2
Von-Misses stress are calculated by using below formula

$$6' = \sqrt{(6x^2 - 6x6y + 6y^2 + 3(\tau xy^2))}$$

$6'$ = 123N/mm^2

VII. FINITE ELEMENT ANALYSIS USING ANSYS

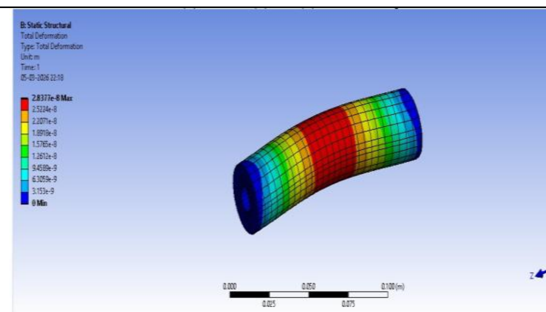

Figure D. Von misses stress and deformation for Case Hardened steel
90 MPa and total deformation obtained is 0.050mm

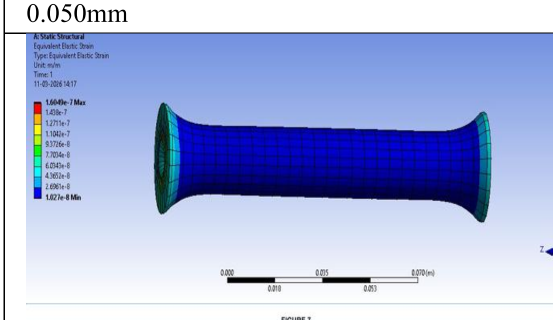

Figure E. Von misses stress and deformation for 34CrNiMo6
65.5MPa, and total deformation obtained is 0.035 mm

VIII. RESULTS

FEA Result Using ANSYS Explicit Dynamics

Sr. No	Material	Mass (kg)	Weight (N)	Von Misses Stress (Mpa)	Total Deformation (mm)
1.	34CrNiMo6	0.070901	0.695546	65.2	0.035
2.	Case Hardened Steel	0.070986	0.69638	90	0.050

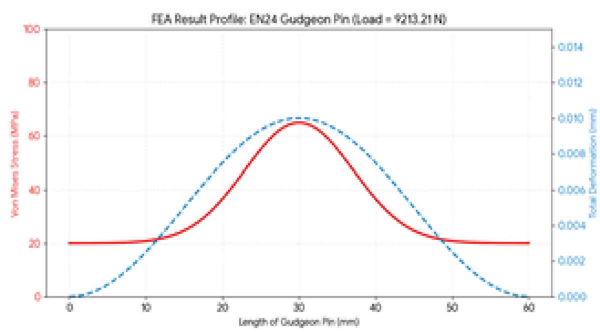

Fig. F.Graphical representation of FEA Result

IX. CONCLUSION

FUTURESCOPE

Also some analysis we conduct such as model analysis and thermal analysis. By selecting different materials and varying properties we can use for modifying gudgeon pin.

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