THERMO-MECHANICAL ANALYSIS OF PISTON RINGS WITH DIFFERENT PROFILES USING FEA

[1]Mohammad Aasif Mafat, [2] Prof. Dhairya Raval
[1] PG Student, [2]Assistant Professor
[1]ME-Mechanical (IC Engine & Automobile),
[1]Silver Oak College of Engineering & Technology, Ahmedabad, India

Abstract : Mechanical Friction is one of the major forms of energy loss in an IC engine. 15 % of total input fuel energy in an IC engine is lost due to friction of various moving parts. A slight modification in component surface/geometry can save a significant part of investment in automotive sector. Piston compression ring is placed on the top position of the piston assembly. Due to simultaneous sealing and sliding reasons, 80% of the piston subsystem is damaged due to mechanical friction. A slight improvement in ring design and its manufacturing method could save significant amount of energy lost due to friction. [1]

Considering this factor, this paper is aimed to identify alternative piston ring profiles, (square, trapezoidal & elliptical) that offer better strength against friction and heat to eventually improve piston and engine life.

An exhaustive survey is carried out to understand the impact of piston rings on engine performance and life as well on material properties and the use of numerical simulation techniques for design optimization. According to the research, a piston ring model will be selected and numerical analysis will be carried out to identify structural and thermal strength of the existing and new piston ring profiles.

***Keywords* –Piston rings, Structural analysis, Thermal analysis, FEA.**

1. INTRODUCTION TO PISTON RINGS

In early steam engines, there was no use of any piston rings. Temperature and steam pressures were not related to today's internal combustion engines, and the need for considering thermal expansions and clearances was smaller. Increasing energy demands require higher temperatures, resulting in a stronger heat expansion of the piston material. It should allow the use of a sealant between the piston and cylinder liner to reduce in the clearance in cold condition. Significantly keeping the clearance between the piston and the liner wall reduces the piston burning gas flow from the combustion chamber past the piston. [2]

The first piston rings used in a machine are the only task of closing the burning chamber, thus preventing burning gases from trailing down into the crankcase. This growth has increased effective pressure in the piston. Rams bottom and miller investigate the behavior of piston rings in steam engines. The Rams bottom, in 1854, built a single piece metallic piston ring. The ring's diameter is 10 percent more than the cylinder bore. When fitted in a groove in a piston, its ring struck against the cylinder. Previous piston rings, multiple pieces of rings and with springs have provided enough sealing power against the cylinder bore. Miller introduces a new one in 1862. This change allows steam pressure to operate at the back of the ring, thus providing more sealing power. This new solution, using flexible rings, is ideal for cylinder bore. [2]

In the early days, the ring was lubricated by the splash lubrication. Subsequently, when the combustion conditions still demanded, higher temperatures, pressure and piston speeds and oil control rings were introduced. A proper lubricating film was required in order to prevent damage on piston, piston rings and liner wall. There were oil control rings, especially designed to distribute the oil and to scrap off the oil to be returned to the crankcase. [2]

2. FUNCTION OF PISTON RINGS

The functions of the piston rings are to seal off the combustion pressure, to supply oil, to control oil and to transfer the heat. The piston is designed for thermal expansion and with gap between the piston surface and liner wall. [2]

3. RING CATEGORIES

Piston rings consists a ring packet, usually with 2-5 rings, with at least one compression ring. The ring in the ring pack depends on the engine type, but usually has 2-4 compression rings and 0-3 oil control rings. For example, fast-speed four-stroke diesel engines have 2 or 3 compression rings and a single oil control ring. Oil control rings which was used in diesel engines are two-piece assemblies and in spark ignited engine oil control ring are three piece assemblies .There are scraper rings which are used for sealing and scarping off the oil from liner wall. [2]

4. LITERATURE REVIEW

Peter Anderson conducted 150-page references to study for giving new light to the tribological issues of the piston assembly. The work is carried out for I.C. engine in general. [2]

P.C. Mishra presents studies related to piston compression ring tribology and the theoretical and experimental works developed to analyze ring liner contact friction. Literature has demonstrated that simulation and experimental work were examined more independently. The limited research work is done in relation to the modeling output with experimental output. Experimental work is also at the basic level to capture data from a running engine. [1]

Ankit Kumar Pandey et al. designed, analyzed and optimized four stroke S.I. engine pistons, using finite element analysis with the help of ANSYS Software. Solid Model of piston has been made using ANSYS 16.2 Geometric module and Thermo-Mechanical (Static Structural Analysis + Steady-State Thermal Analysis) analysis is done to analyze stresses, total deformation and factor of safety distribution in various parts of the piston to know the effect due to gas pressure and thermal variations using ANSYS 16.2. Piston optimized using Response Surface Optimization module. The thickness of piston barrel is reduced by 52.28%, the thickness of the piston crown head increased by 9.41%, the width of top land increased by 3.81%, axial thickness of the ring is increased by 2.38% and radial thickness of the ring reduced by 5.31%, resultant mass of the piston reduced by 26.07% and it's factor of safety increased by 3.072%. [3]

Luiz G.D.B.S. Lima et al. conducted a series of FEA analysis to analyze the stresses in thin coated piston rings under contact loads. Four values of thickness (20 to 100 micrometers) were analyzed, with five elastic ratings (144 to 578 GPa) each. Results (a) if the film is thick, the compressive stress is low at the interface. (b) if the film is thin, the compressive stress is high.[4]

Tejaskumar Chaudhari et al. compared theoretical modeling of friction force from the various sources of friction to experimental results for analyzing the tribological characteristics. Proper sample of Piston ring and cylinder liner pair has been developed to study various tribological parameters on reciprocating tribometer. Variable parameters are analyzed with engine speed, oil viscosity, and load. The experimental results and observations has been studied with varying operating conditions ranging from 300 rpm to 1500 rpm and constant load of 60 N. It is assumed that speed increases, friction force and friction coefficients also decrease. [5]

A large part of heat which is produces during combustion of fuel is conducted to the cylinder liner, reduces the hardness and causes oxidation and evaporation of oil on the upper cylinder walls.

Lubrication condition mainly depends on the oil quality, interaction of nearby rings, surface quality and cylinder bore deformation. The strength of the piston rings can be enhanced with the help of surface coatings that help reduce compressive and axial stresses. Piston ring profiles can be changed to improve its useful life.

With the research data collected so far, it is evident that the piston ring geometry can be optimized to improve heat transfer rate, minimize stress, reduce friction and eventually reduce mechanical loss. Finite element approach can be utilized to identify ring profile and evaluate the stress and strain due to structural and thermal loads within the engine cylinder.

M.Srinadh et al. designed a piston for 1300cc diesel engine car and taken 3 different profile rings .A 2D drawing is created from the calculations. The piston and piston rings are modelled using Pro/Engineer software; the stress and displacement are analyzed for the piston and piston rings by applying pressure on it in Structural analysis. By observing the analysis results, we can decide whether our designed piston is safe or not under applied load conditions. [9]

The thermal flux, thermal temperature distribution is analyzed by applying temperatures on the piston surface in Thermal analysis. The structural and thermal analyses were also done on the piston and piston rings model using Cast iron, Aluminum Alloy A360 and Zamak. [9]

By comparing both the material analysis and decided which material is better for manufacturing of Piston and piston rings. Structural and Thermal analysis were also performed in ANSYS software. [9]

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The thickness of piston barrel is reduced by 52.28%, the thickness of the piston crown head increased by 9.41%, the width of top land increased by 3.81%, axial thickness of the ring is increased by 2.38% and radial thickness of the ring reduced by 5.31%, resultant mass of the piston reduced by 26.07% and it's factor of safety increased by 3.072%. [10]

5. MATERIAL & PROPERTIES

Table No. 5.1 Material: Stainless Steel AISI 420 [6]

	Stainless Steel AISI 420
Poisson Ratio	0.24
Modulus of elasticity (MPa)	2×10^5
Thermal Condusctivity (W/m K)	30
Ultimate Tensile Strength (MPa)	640
Yield Tensile Strength (MPa)	390
Density (kg/m^3)	7800

6. RESEARCH METHODOLOGY

Static Analysis can be used to determine displacements, stresses etc. Both linear and non-linear static analyses, Non liniearities include plasticity, stress stiffening, deflection, strain, elasticity, contact surface and creep. Calculate the temperature distribution and related thermal quantities in a thermal analysis. Typical thermal quantities of interest are:

- The temperature distributions
- The amount of heat lost or gained
- Thermal gradients
- Thermal fluxes.

6.1 3D drawing of piston rings

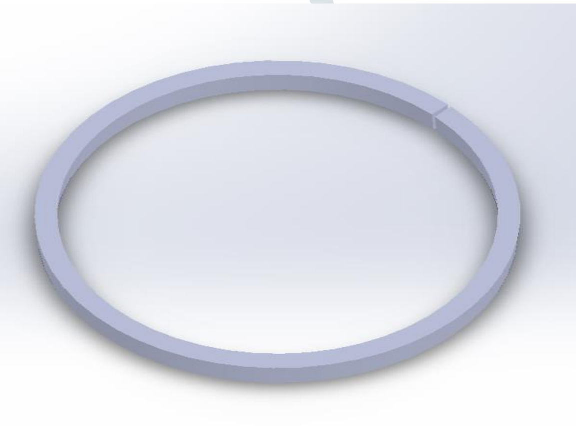

Fig. 6.1 Square piston ring 3D model

Fig. 6.2 Trapezoidal piston ring 3D model

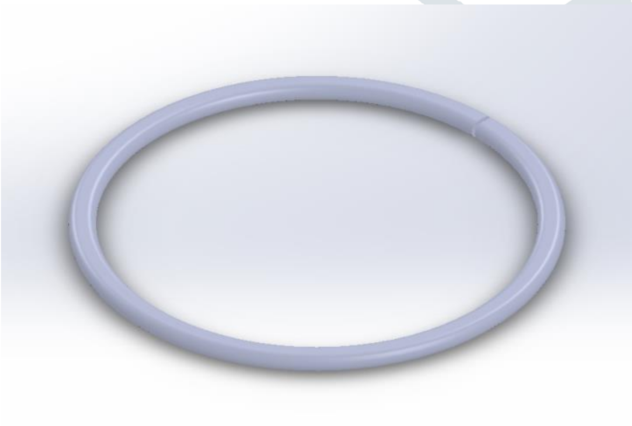

Fig. 6.3 Elliptical piston ring 3D model

6.2 Boundary Condition for Structural & Thermal analysis of Piston Rings

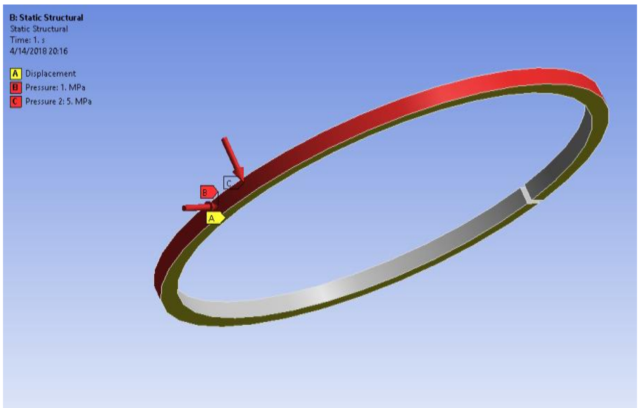

Fig. 6.4 Boundary condition for structural analysis

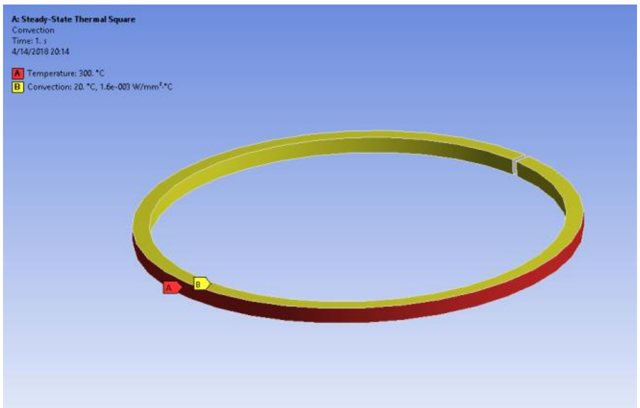

Fig. 6.5 Boundary condition for thermal analysis

6.3 Simulation of piston rings

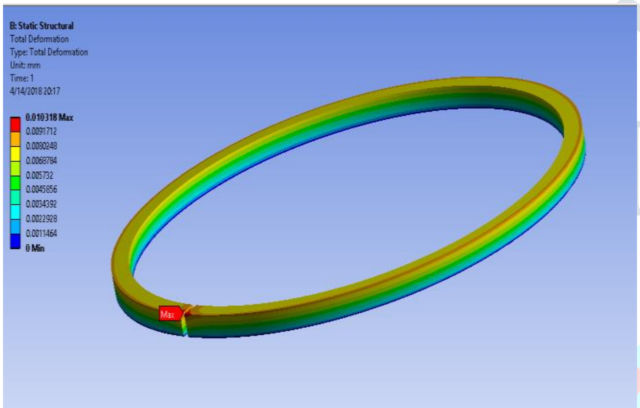

Fig. 6.6 Deformation of square ring

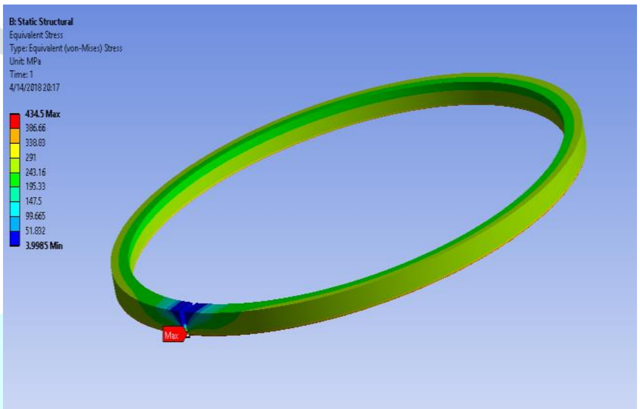

Fig. 6.7 Distribution of von-mises stress of square ring

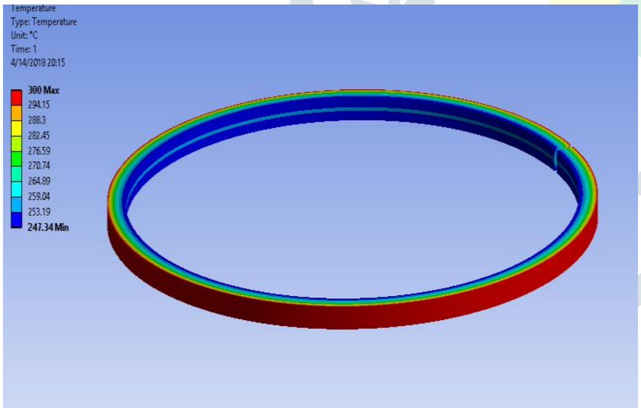

Fig. 6.8 Temperature distribution of square ring

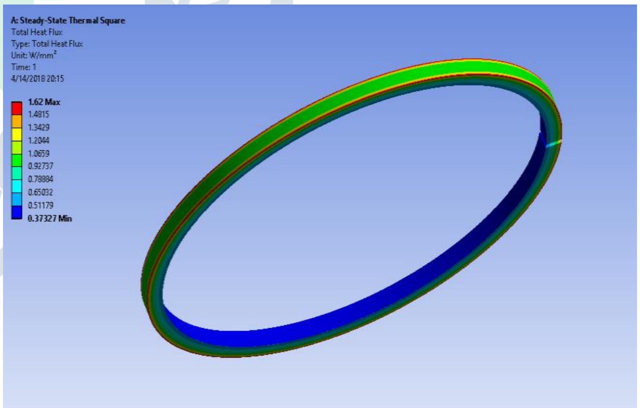

Fig. 6.9 Total heat flux of square ring

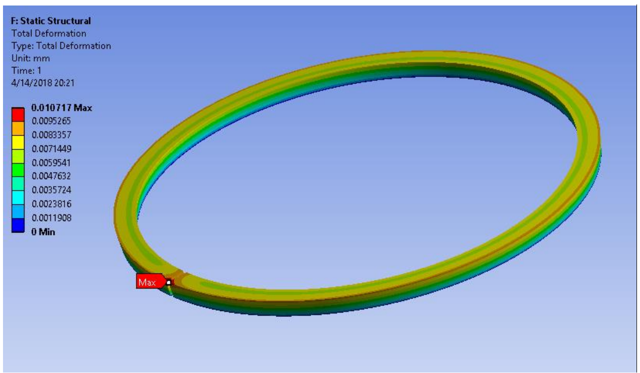

Fig. 6.10 Deformation of trapezoidal ring

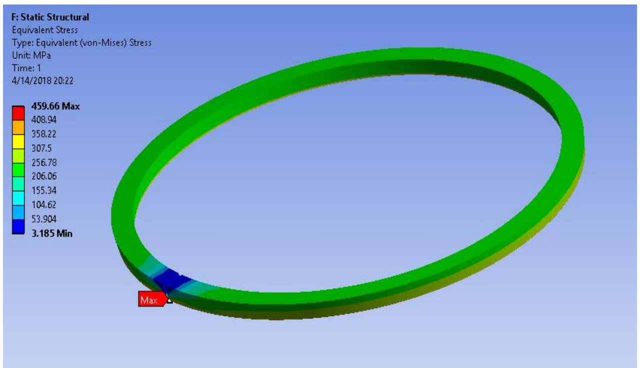

Fig. 6.11 Distribution of von-mises stress of trapezoidal ring

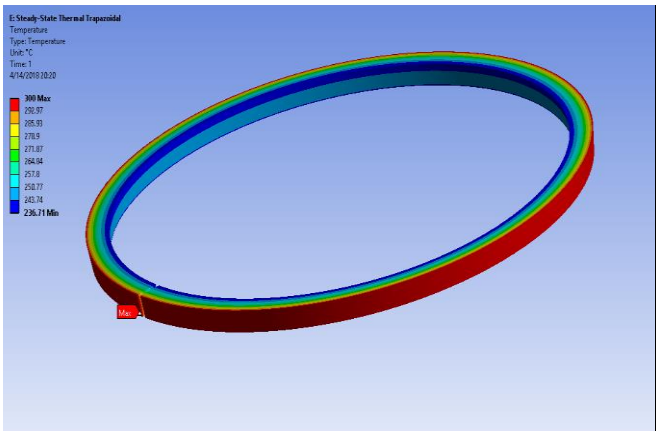

Fig. 6.12 Temperature distribution of trapezoidal ring

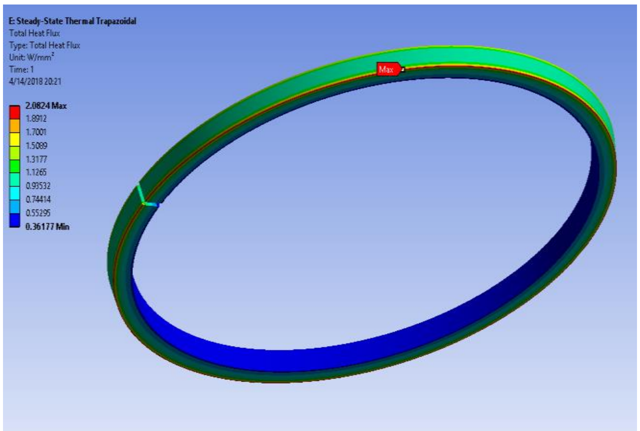

Fig. 6.13 Total heat flux of trapezoidal ring

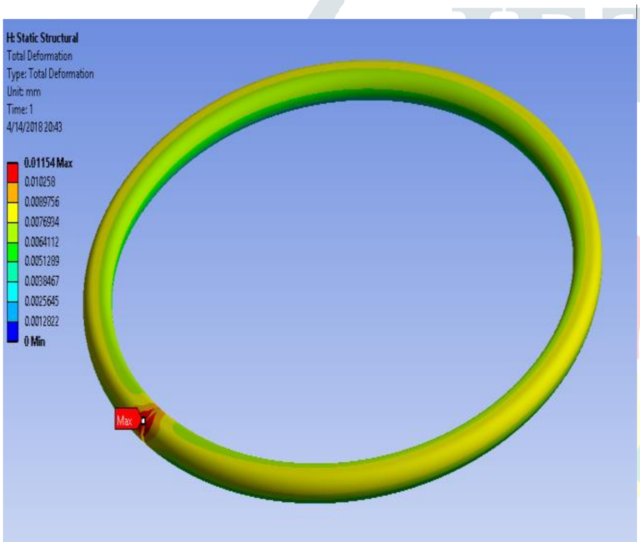

Fig. 6.14 Deformation of elliptical ring

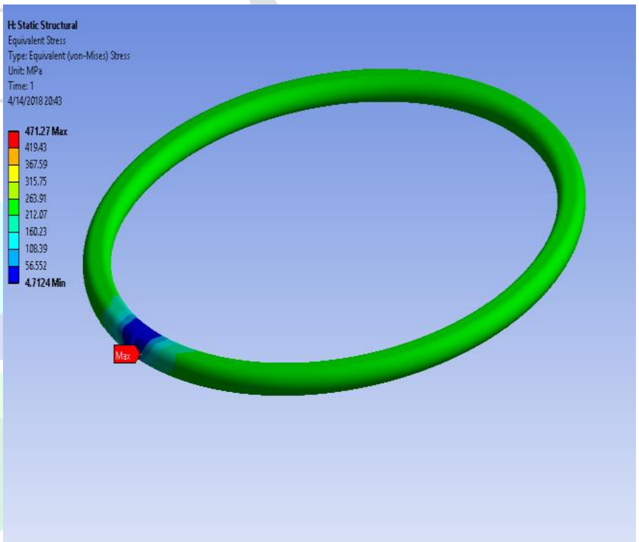

Fig. 6.15 Distribution of von-mises stress of elliptical ring

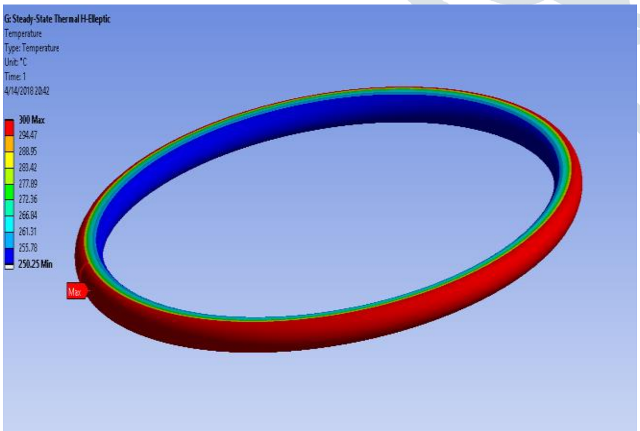

Fig. 6.16 Temperature distribution of elliptical ring

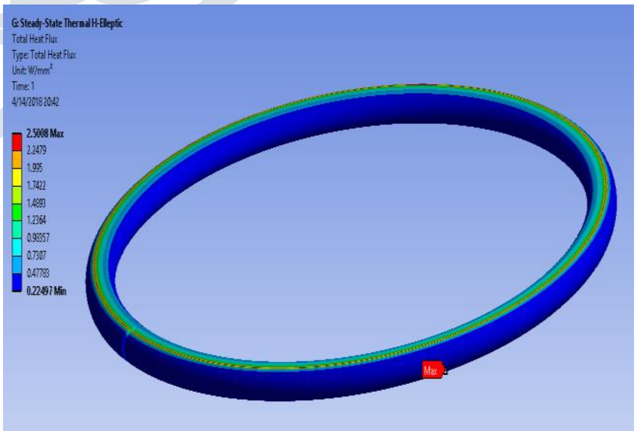

Fig. 6.17 Total heat flux of elliptical ring

7. RESULTS & COMPARISON

Table No. 7.1 Comparison of Deformation

Ring Profile	Deformation (mm)
Square	0.010318
Trapezoidal	0.010717
Elliptical	0.01154

Table No. 7.2 Comparison of Stress

Ring Profile	Von-Mises Stress (MPa)
Square	434.5
Trapezoidal	459.66
Elliptical	471.27

Table No. 7.3 Comparison of Heat Flux

Ring Profile	Heat Flux (W/mm^2)
Square	1.62
Trapezoidal	2.0824
Elliptical	2.5008

8. CONCLUSION

Piston ring's calculations are done for two wheeler Honda Splendor engine. In the analysis piston rings was analyzed using three different profiles namely Square, Trapezoidal & Elliptical. In three different profiles elliptical ring is best as per ansys results in deformation, stress & heat flux. The deformation & stress values for elliptical profile ring are high which is also within permissible limit. The heat flux value is high for elliptical ring profile compare to other ring profile. So, as per values elliptical ring profile is having good value so we can use elliptical ring profile.

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