Experimental investigation on different patterns of laser surface texturing (LST) on piston ring for friction power reduction in multi cylinder I.C.Engine.

A Synopsis of the Ph. D. Thesis

Submitted to

Gujarat Technological University, Ahmadabad

for the award of

Doctor of Philosophy
in
Mechanical Engineering
By

PATEL VIJAYKUMAR KANTILAL
[Enrollment No.139997119012]

Under the Supervision of

Dr. Bharat M. Ramani
Supervisor

Principal & Professor
Shri Labhubhai Trivedi Institute of Engineering and Technology,
Rajkot, Gujarat, India

GUJARAT TECHNOLOGICAL UNIVERSITY
AHMEDABAD

NOVEMBER-2020

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EXPERIMENTAL INVESTIGATION ON DIFFERENT PATTERNS OF LASER SURFACE TEXTURING (LST) ON PISTON RING FOR FRICTION POWER REDUCTION IN MULTI CYLINDER I.C.ENGINE

Abstract:

Due to depletion of the natural resources at one hand and increase in number of automobile vehicles on other hand the natural fuel may be extincted in near future. Reduction in fuel consumption has therefore become an extremely important concern for the automotive industry today. With an increasing demand for greater durability and decreased oil consumption in an internal combustion engines, it has become necessary to reduce the power losses to boost the engine performance. Engine piston and bore surface finish significantly influences lubrication oil consumption, as well as wear characteristics. More than 40% of power developed by an internal combustion engine is spent in overcoming the friction and wear of various components and not only this but these parts are damaged frequently due to excessive wear, reducing their self life. Therefore, by reducing friction and wear the performance of the engine can be enhanced, however complete elimination of friction and wear is not possible. The frictional losses can be reduced by proper selection of lubricating oil, the material of mating components and surface microstructure of material used in internal combustion engine.

The present work focuses on the friction power reduction by changing the surface microstructure of piston rings to enhance the performance of petrol engine with the help of Laser Surface Texturing (LST) technique. Laser surface texturing (LST) is mainly used to reduce the contact surface between the piston and the cylinder. Micro-structure of frictional surface studied first and accordingly they has been replaced with various texturing patterns. An experimental set up has been developed with all required instrumentation in order to study and investigate the effect of LST on the engine performance.

Piston ring with dimple textured is designed, fabricated and used in the motor-driven engine to study the frictional characteristics and compared with an untextured piston ring. Therefore this research work presents detailed study including the fabrication and analysis of three different patterns made by Laser Surface Texturing method to see its effect on the reduction of friction power with different lubrication oils. Each piston ring pattern has been tested on the developed Maruti 800CC multi-cylinder engine in standard condition. The series of experiments has been carried out on developed multi-cylinder I.C.Engine test rig under different speeds, load etc. The study includes

three different piston ring patterns namely, full width, symmetrically at both sides and centered portion texturing with two various lubricating oils namely SAE20W40 and SAE20W50. The systematic data has been recorded and observations have been discussed in the details.

From this detailed study it has been concluded that there is a substantial reduction in the friction power of the engine with the use of LST on the piston rings. It is further observed that with full width texturing on piston ring consumes 26% less power in comparison to non-textured piston rings and similarly, 15% and 9% respectively in the case of both sides LST and Centered portion LST with SAE20W40 lubricating oil. It is further concluded that there is a definite effect of lubricating oil on the friction power along with LST. With SAE20W50 lubricating oil the percentage of reduction of friction power for all three LST has been observed as 29%, 19% and 10% respectively, that means additional reduction of 3% in case of full width LST, 1% with both sides LST and 4% with central portion LST is observed with SAE20W50.

Due to the reduction in friction between two matching parts in I.C. Engine, reduces fuel consumption, increased power output of the engine, reduced oil consumption and reduction in exhaust emissions in the engine. It ensures the smooth running of the engine with better performance and higher thermal efficiency. Brake power is increased by reducing friction power with the help of LST on piston ring in I.C. engine which indirectly increases thermal efficiency of I.C.Engine.

Introduction

Internal combustion engine (I.C. Engine) has gained the name and frame in serving the society in many ways especially like modern transportation. Small petrol vehicles occupy quite a big share for domestic, commercial, agriculture and residential vehicles. Therefore, petrol engines are the key component of routine life and performance improvements are usually the priority. To achieve the overall economy in transportation, the smooth running of the engine is desirable. The main attractions of the internal combustion engine are higher fuel potency, ruggedness in construction, simplicity in operation, and easy maintenance. But due to friction, we may not be able to avail its services for a long time. So efforts are made to make global efforts to reduce friction between various parts of the internal combustion engine. The friction loss in an internal combustion engine is the most important factor in determining the fuel economy and performance of the vehicle utilizing the power of the engine. The constant requirements to improve the reliability and efficiency of mechanical components and in particular to reduce friction losses make friction control more important. Lots of work is being done to reduce friction in moving parts of the engine to improve its overall performance. The most important part of the total mechanical losses in the engine is the friction between the piston ring and cylinder system approximately 50-60% of which 70-80% comes from piston rings.

Proper lubrication and surface formation are the main issues of reducing friction in piston/cylinder systems and therefore have attracted much attention in related literature. The surface structure is known for many years as an instrument for increasing the tribology properties of mechanical components. Perhaps the most familiar and early commercial use of surface texting in the engine is cylinder liner honing. As a potential new technology to reduce friction in mechanical components, surface texting has emerged in general and laser surface texting (LST) in recent years. In this work, the surface microstructure of piston rings is changed by Laser Surface Texturing method, to change the lubrication regime of surface, and wear-resistant. Comparison with base data, compared to the piston ring with fully textured, partial textured and friction data, non-textured piston rings.

Brief description on the state of the art of the research topic

In an I.C. engine, there is a number of parts that comes in to contact with each other during their motion. So, friction is bound to be there. To obtain maximum efficiency of an engine, it is required to reduce this friction force. After conducting lots of experiments on an engine, scientists are come to know that the friction forces in an I.C. Engine are in the tune of 17-19 % of total input power. The contribution of various experimented and estimated frictional losses reported by different scientists is as under. The state of art of this works is mentioned in Table 1.

Table 1 frictional loss in the I.C. Engine system

Scientists	**Total losses**	**Piston ring assembly**	**Value system**	**Crank/ Engine bearing**	**Auxiliaries [Pumping]**	**Remarks**
Heywood J.B.	17 %	35-45%	10-15%	20-30%	20-10%	----
C.M.Taylor	---	45 %	10%	25%	----	----
M. Hoshi	17-19%	45%	7.5%	37%	10%	SAE20W40@1500 rpm
Domkundwar	13%	40%	7%	33%	20%	----
R.I. Taylor	----	42%	19%	39%	----	SAE15W40@2500 rpm

Yakio Tateshi	17%	35%	10%	35%	20%	-----
R.P. Sharma	----	40-50%	7-15%	20-30%	20-25%	-----
R.I.Taylor	---	40%	25%	35%	-----	SAE30@2500 rpm
R.C.Coy	----	46%	34%	20%	---	SAE15W40@2000 rpm

Table 2: Summary of literature survey related to LST on piston rings for friction.

Author	**Year**	**LST**	**Result**	**Variable Parameters**
Aviram Ronen et al.	2001	With spherical dimples	30 % reduction in friction.	Entire ring surface in contact with the cylinder liner was textured.
A.Ronen et al.	2001	Pores textured “Piston ring” and “Cylinder liner” surfaces.	15% reduction in friction.	Takes into account inertial forces and the effects of compression of the film due to the set of piston rings and radial velocity respectively.
G.Ryk and I.Etsion	2005	Piston rings with partial surface texture.	Partial LST piston rings exhibited about 25% lower friction.	With a range of nominal contact pressure from 0.1 to 0.3 MPa and within speed limit from 500 to 1200 revolutions per minute.
Y. Kligerman et al.	2005	Full LST ring	30% for narrow rings to 55% for wide rings.	The minimum average friction force for partial LST piston rings has been observed to be much less than the optimum full LST ring.
G.Ryk et al.	2005	Only a portion of the piston ring width is textured with high dimple density.	40% reduction in friction.	Experiments were carried out with full LST piston rings in the shape of a barrel and not with conformal cylindrical rings.

Definition of the Problem

"Experimental Investigation on different patterns of Laser Surface Texturing (LST) on piston ring for friction power reduction in multi-cylinder I.C.Engine"

Objective and Scope of work

It evolves the very clearly from the above literature survey, there is a need and potential to study the reduction in friction between piston-cylinder assembly by using laser surface texturing piston ring in a petrol engine is primary research objective. The secondary objective of the research is to investigate the reduction in friction power, In this way, we can increase the power of the engine (output power or brake power), mechanical efficiency and thermal efficiency, in light of this the following objectives are laid down in the present research.

- Identify and numerically quantify the parameters of laser surface texturing and optimize them for better performance of the Internal Combustion Engine.
- To design and produce special texture piston rings to investigate its effect on the performance of the Internal Combustion Engine.
- Design, Develop and Operate the Experimental set of multi-cylinder I.C.engine test rig, equipped with all necessary measuring instruments to study the effect laser surface texturing on the performance of the Internal Combustion Engine.
- Conduct sets of the experiment with a defined pattern of LST on piston ring with controlled environment condition and experimentally analysis of the effect LST on friction power with different type grade of lubrication oil.
- To study, investigate and compare the performance of Internal Combustion Engine with and without laser surface texturing ring on the piston.
- To carry out uncertainty analysis of measure quantities/parameters and their effect on the final result.

Scope of work

During the research work, it is felt that certain areas required future attention. These areas are listed below.

- The life cycle analysis can be examined with a different pattern of texturing on piston ring
- The application of the selective coating on piston rings with Laser surface texturing can reduce wear and prolonged engine life by increasing the life of pistons and increasing the effectiveness of lubrication oil. This area remained unnoticed in the present research work.

- The role of “Oil ring laser surface texturing” needs to research.
- Experiments are carried out on stationary test rig without the effect of Air-cooling to the engine so it is suggested to experiment with an engine through pedestal fan (Similar to moving vehicle Air-cooling).
- The detailed Combustion Characteristic and exhaust gas analysis can be carried out in the future.

Original contribution by the thesis

- Identification of research problem after a literature survey is reflected in the review paper published in UGC approved Journal.
- Design and develop different patterns of laser texture on piston rings. This work is reflected in the research paper published in the Journal of Ambient Energy, A Taylor Francis Journal.
- Development of multi-cylinder I.C. Engine test-rig under different variable i.e. speed, lubricants & ring geometry which can measure friction power, the temperature at TDC & BDC of each cylinder, Inner and outer bearing temperature and Lubrication oil temperature with controlled environment condition with sets of engine speed repeatability. This work is reflected in the research paper published in the Journal of Ambient Energy, A Taylor Francis Journal.

Methodology of Research, Results / Comparisons

The present experiment research work comprises friction power reduction by three different patterns of laser surface texturing piston ring (i.e full width, center portion and symmetrically both side) with un-textured piston ring.

(a) Experimental setup description

The Maruti 800CC multi-cylinder internal combustion engine experimental set up is designed and fabricated as shown in Figure 1 to study the effect of surface texture on column compression rings (Top ring and second ring), To measure energy usage, the engine is combined with the variable external power engine. Speed, lubricants, laser texture textured ring of the piston and coolant exposure at various points within the piston-cylinder system (TDC, BDC) were measured in various operative conditions. A system consisting of the crank mechanism, a piston cylindrical head and the engine lubrication system with no engine cooling system and gearbox. The crankshaft is connected to an induction motor to drive the engine, as shown in Figure 1. A tachometer is used to measure the rotational speed of the engine. It displays the RPM in a digital number. The Variable Frequency Drive (VFD) used to measure the power consumed in the engine at different engine speeds. RTD (Resistance Temperature Detector) (thermocouples) sensors are installed at different nine locations to measure engine temperature as shown in Figure 1. Sensors T_1, $T_{3,}$ and T_5 located at

18mm from the top surface of the engine and sensors T_2, T_4 and T_6 located at 18mm from the bottom surface of the engine. Distance between T_1-T_2, T_3-T_4, and T_5-T_6 is 36mm.

Maximum temperature rise at the middle of the stroke length due to friction between piston rings and cylinder wall and increased piston velocity relative to either the TDC or BDC. Two sensors are mounted in the middle of the upper half and the lower half of the stroke length for each cylinder to cover both region of stroke length (Upper half & Lower half) and to obtain a more precise temperature reading. Both sensors should not be positioned in the middle of the stroke length.

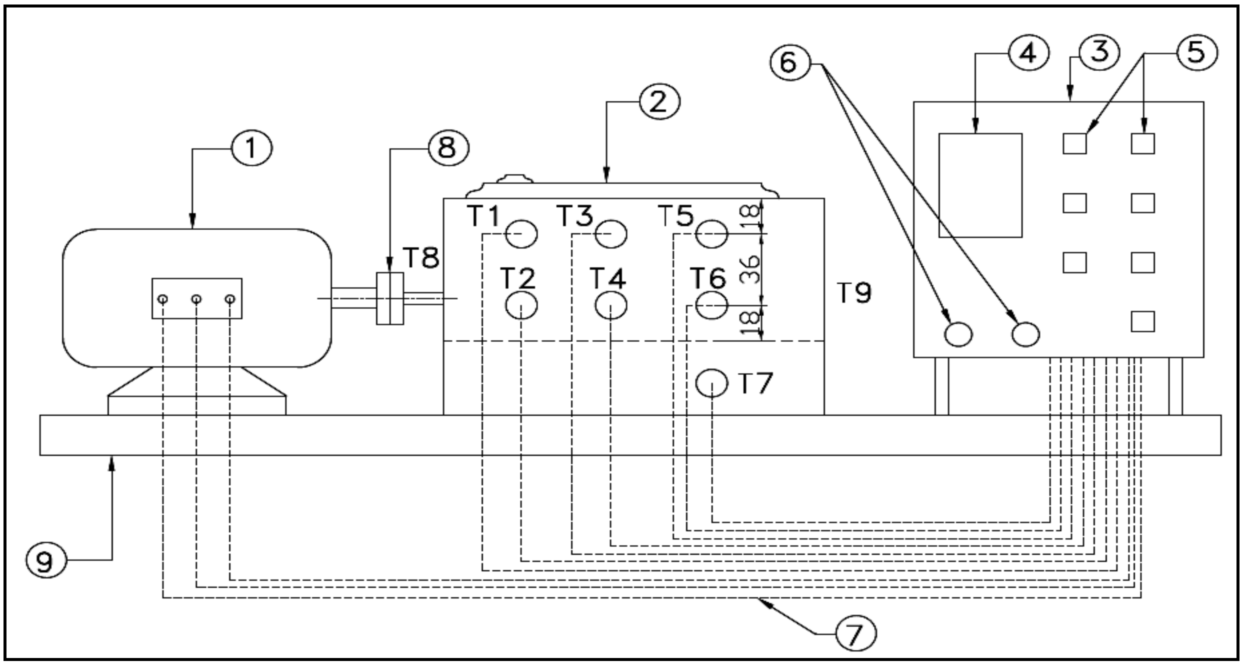


Figure 1. Schematic diagram of the experimental setup

1. Electric motor	T_1 = Temperature sensor at top dead center for cylinder -1
2. I. C. Engine	T_2 = Temperature sensor at bottom dead center for cylinder -1
3. Electrical panel	T_3 = Temperature sensor at top dead center for cylinder -2
4. Variable frequency drive	T_4 = Temperature sensor at bottom dead center for cylinder -2
5. Temperature display device	T_5 = Temperature sensor at top dead center for cylinder -3
6. Control panel	T_6 = Temperature sensor at bottom dead center for cylinder -3
7. Electric wiring	T_7 = Temperature sensor at lubricating pan for lubricating oil
8. Coupling	T_8 = Temperature sensor for inner bearing temperature
9. Base	T_9 = Temperature sensor for outer bearing temperature

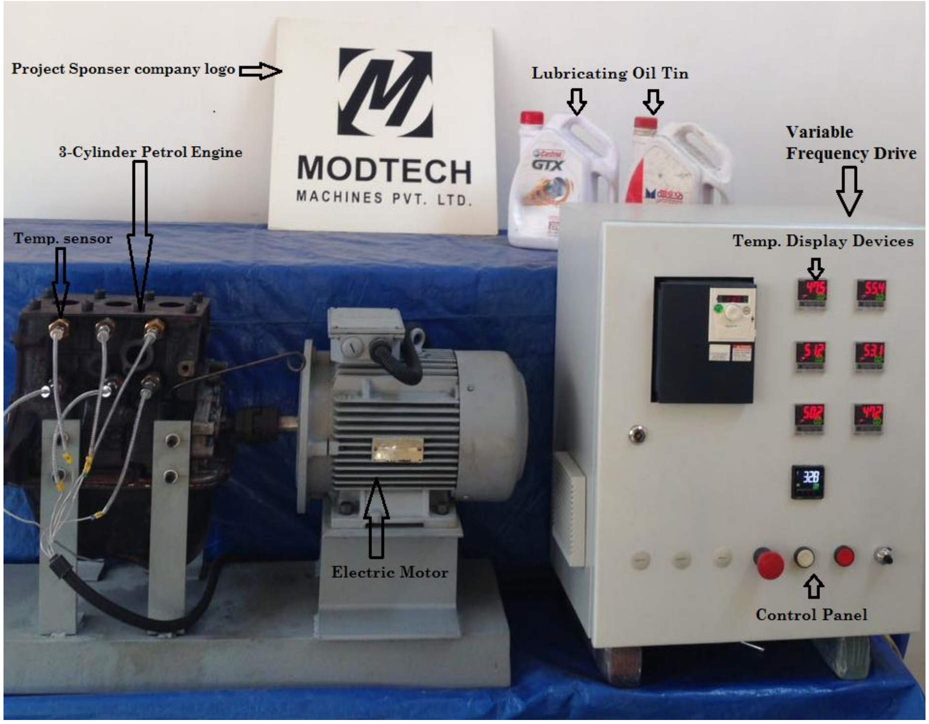
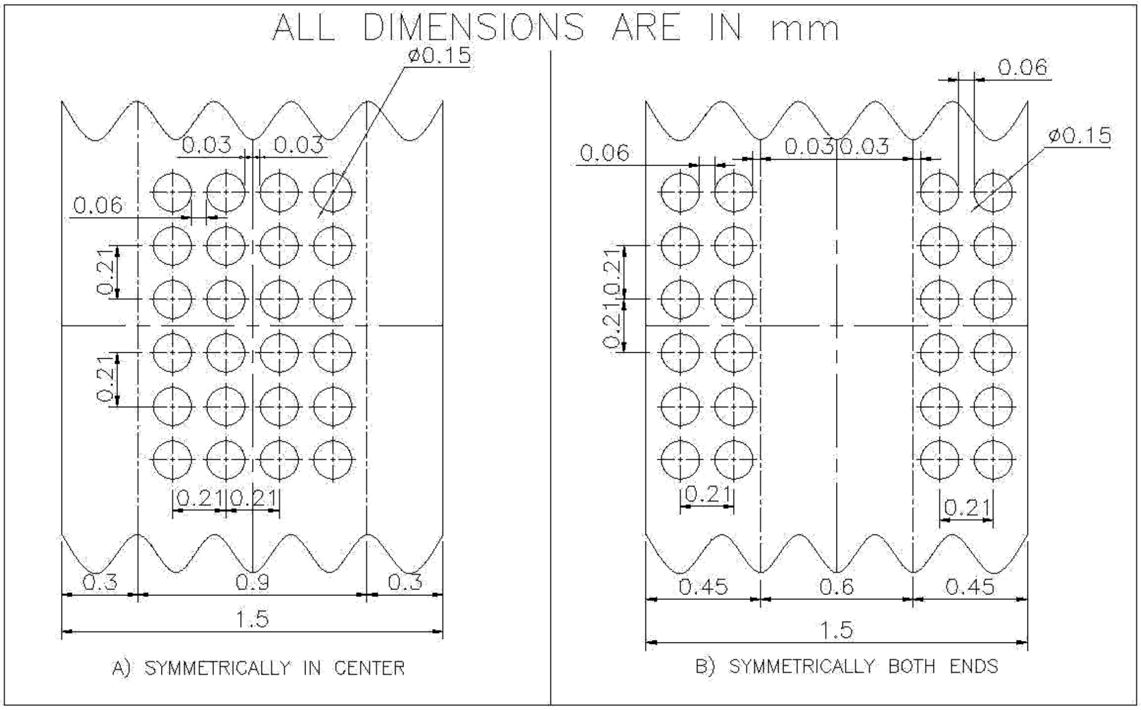


Photo-1. A photographic view of Actual Multi-Cylinder Engine Test Rig

(b) The pattern of texture:



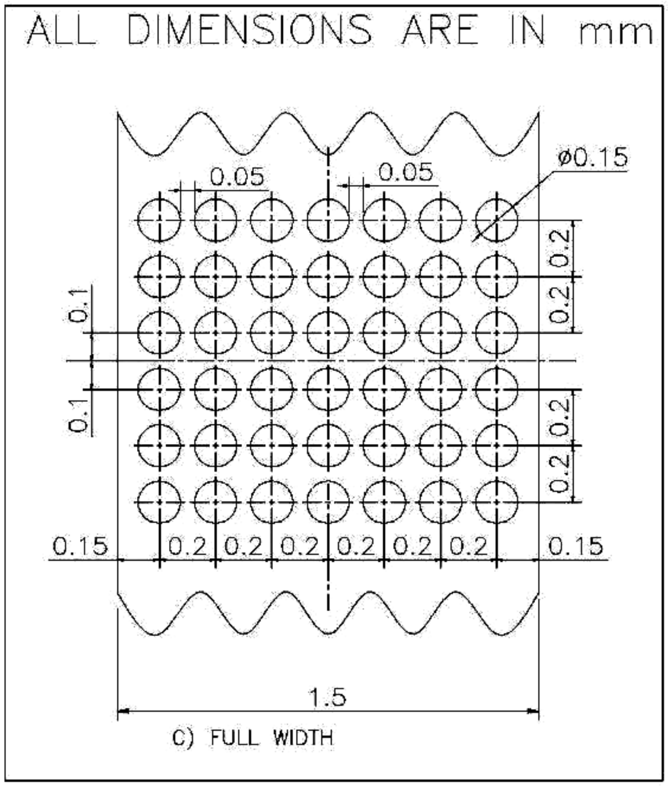
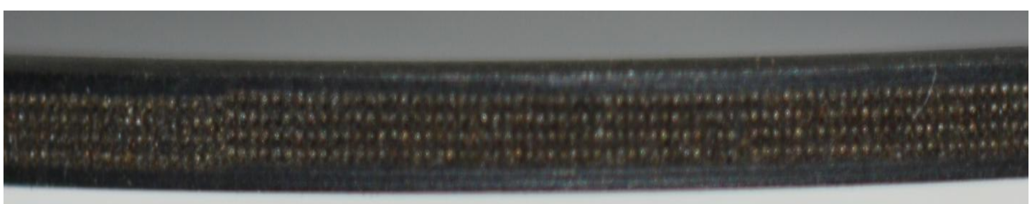
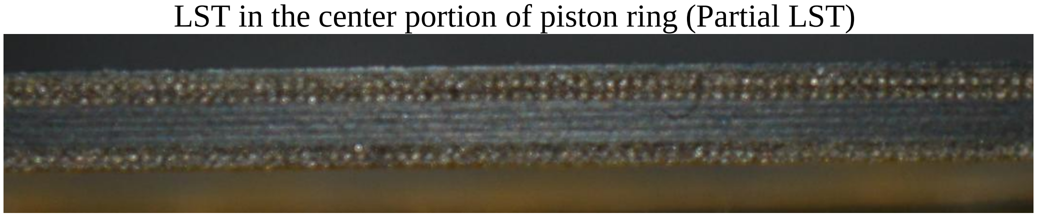


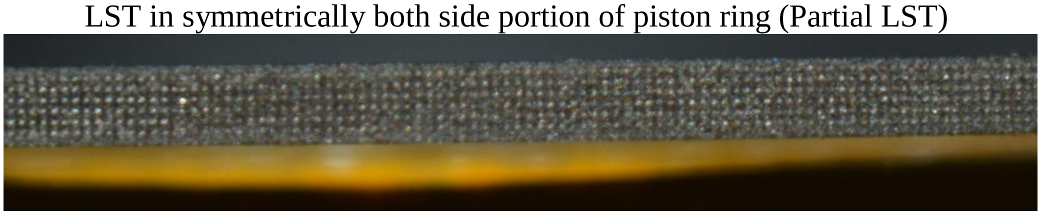
Figure 2. Drawing of LST Pattern on piston ring



LST in the center portion of piston ring (Partial LST)



LST in symmetrically both side portion of piston ring (Partial LST)



LST on the full-width portion of piston ring (full LST)

Photo 2. Photos of actual piston rings with different types of patterns

Fig.2 shows the AutoCAD drawing of piston ring having a face width of 1.5mm. In Fig. 2 (a) central portion of the piston ring is partially textured with dimple diameter of 150μm uniformly having dimple depth of 12μm. Center distance between two dimples is 0.21mm while the end distance is 0.06mm.On each side of the central line, there are two columns of dimples. Total 0.9mm width is covered with textured portion and 0.3mm is untextured portion on both sides. Similarly, in Fig. 2(b) width of 0.45mm symmetrical at both axial ends of the piston ring is textured and 0.6mm middle portion is untextured. In Fig. 2(c) entire width of the piston ring is to be textured. Hence the total area density of the dimples is 50%.

The following optimized parameters have been used for the experimental study

- Dimple diameter, 2rp = 150 μm
- Dimple depth hp = 12 μm
- Width of the textured portion of the piston ring, Bp = 0.9 mm
- The area density of the dimples, Sp = 0.5

(c) Experimental methodology

A series of experiments were carried out on the developed multi-cylinder (3-cylinder) in-line I.C.Engine set up with different speeds, lubricants and ring geometry. In this work, the motored engine friction test method (strip method) is used. Tests were conducted at 400 RPM in an increment of 200; the maximum is 3000 RPM. Initially, the system works for at least 5-10 minutes, so that the system stabilizes and lubricating oil correctly reaches the surface of the piston ring and cylinder liner. After obtaining a stable state, measurement of actual power consumed, engine rpm and temperature at eight different locations on the engine are noted with RTD (Resistance Temperature Detector) sensors. Next, to enable the next set of measurements, the frequency of VFD is altered. The speed is varied without switching off the power by varying the frequency on VFD. The experiments have been performed in a controlled environment for similar boundary conditions by using the air conditioner room having 23°C temperature as per Standard Ambient Temperature and Pressure Conditions (SATP). The experiments have been repeated in increasing, and decreasing order of engine speed and no fluctuations were observed in the reading. Comparing the reading with basic reading (without LST piston ring) by plotting graphs and charts. Table 1 shows the complete specification of the engine used in the present experiment.

(d) Specifications of the I.C.Engine:

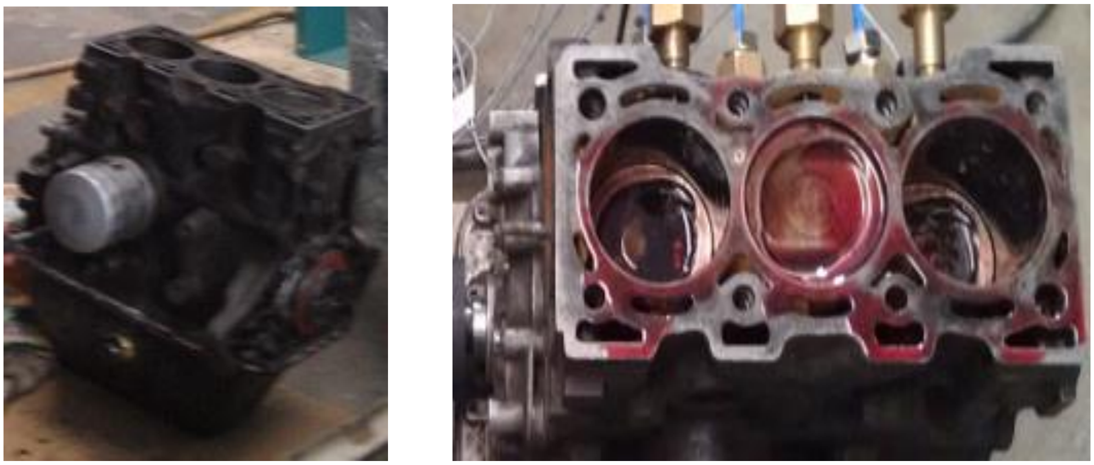


Photo-3 Maruti 800 C.C. 3-cylinder inline petrol Engine (Front view & Top view)

Table 3. Complete engine setup of Maruti 800CC Vehicle

TYPE	4 Stroke Cycle Water Cooled
Displacement	796 C.C.
Bore diameter	68.5 mm
Stroke length	72 mm
Compression ratio	8.7:1 mm
No. of Cylinder	3

(e) Uncertainty analysis:

- ❑ The uncertainty in RPM =±1rpm.
- ❑ The uncertainty in temperature =±0.01°C
- ❑ The uncertainty of power = 0.081%.
- ❑ The uncertainty in frequency in Variable frequency drive =± 0.01HZ

(f) Results :

Four series of experiments have been performed to investigate the advantage to use LST in the reduction of friction. The first consists of without use texturing and the remaining three contain texturing surfaces. Hence, first, one is taken as reference one for comparison purposes with another three textured surfaces.

A comparison between the use of LST in the piston ring and with use of LST is presented in this section. Fig, 3 shows the variations of Friction power consumption vs speed for various LST methods applied on the piston rings. It is clearly shown that, when the speed of the engine increases, at the same time the friction power consumption increases hence, the trends are shown equally in all the cases and found similar trends as investigated. The reason behind the increase in friction power consumption is the increment in contact between the piston and wall of the cylinder. This also found that, in the case of the full-width LST method on piston ring, the friction power consumption found lower as compared with both cases.

Without the use of LST, the whole surface of piston contact with a liner of the cylinder. Hence, friction between piston and cylinder liner will be higher, hence the friction power found higher. Here, in the case of symmetrically at both sides, only the edges of the piston ring are in contact with the cylinder liner, hence friction found but not higher as compared with out of LST. A center portion of the piston ring normally groove, hence both sides of the contact with the cylinder liner, and therefore the friction will be less as compared with the previous two cases. In the Full-width case, the density of the LST will be lower due to the area as compared with the previous three cases and found lower friction power consumption.

Following figure 3 illustrates the relationship between engine speed and friction power consumption. It is observed that the power consumed is more without LST due to friction. The friction power losses decrease significantly with LST due to the provision of LST on the piston ring.

(g) Effect of various LST on frictional power

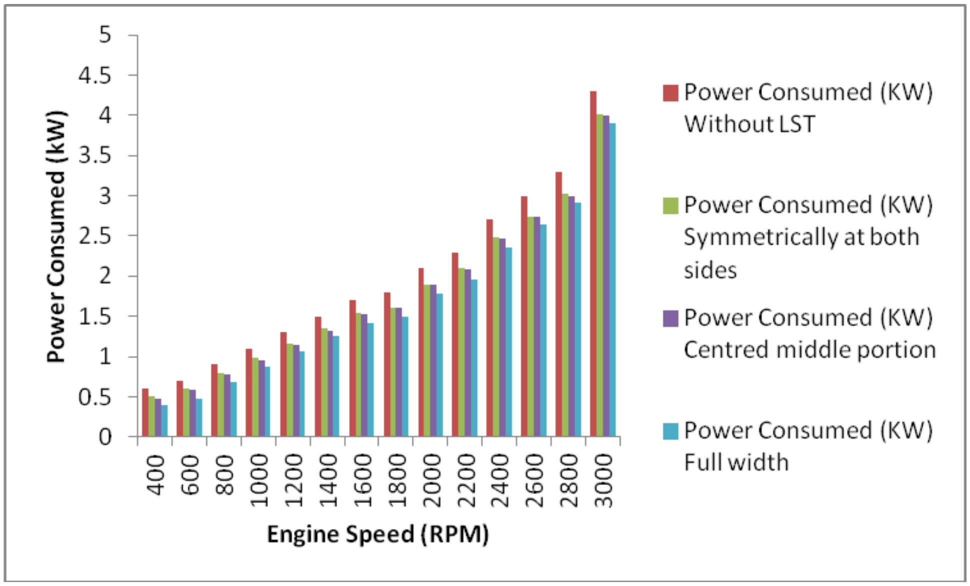


Figure 3. Engine speed vs power consumed for various textured surfaces and without a textured surface

Table 4. Comparison table percentage of friction power reduction for various textured surfaces with two type's lubrication oil

Types of LST Pattern on piston ring	Lubrication Oil	
	SAE20W40	SAE20W50
Without LST	Used as a base data	
Symmetrically on both sides	09.36 %	10.71 %
Central portion	15.43 %	19.57 %
Full width	26.07 %	29.21 %

Achievements with respect to objectives

Objectives	Achievements
✓ Identify and numerically quantify the parameters of laser surface texturing and optimize them for better performance of the Internal Combustion Engine.	✓ The required parameters are to be identified and made numerically quantified and optimized parameters to be selected to carry out experimentation for investigating.
✓ To design and produce special texture piston rings to investigate its effect on the performance of the Internal Combustion Engine.	✓ Three different (Centered portion, symmetrically both sides and full width) dimple patterns developed on piston ring.
✓ Design, Develop and Operate the Experimental set of multi-cylinder I.C.engine test rig, equipped with all necessary measuring instruments to study the effect laser surface texturing on the performance of the Internal Combustion Engine.	✓ The Maruti 800CC multi-cylinder internal combustion engine experimental set up (test rig) is designed, fabricated and equipped with all necessary measuring instruments to study the effect laser surface texturing on the performance of Internal Combustion Engine.

✓ Conduct sets of the experiment with a defined pattern of LST on piston ring with controlled environment condition and experimentally analysis of the effect LST on friction power with different type grade of lubrication oil.	✓ Four series of experiments have been performed to investigate the advantage to use LST on piston ring in the reduction of friction power. ✓ The first consists of without use texturing and the remaining three contain texturing surfaces. Hence, first, one is taken as reference one for comparison purposes with another three textured surfaces. ✓ The experiments have been performed in a controlled environment for similar boundary conditions by using the air conditioner room having 23°C temperature as per Standard Ambient Temperature and Pressure Conditions (SATP). ✓ For finding out the effect LST on engine friction power with different type grades of lubrication oil critical analysis of experimental results has been carried out.
✓ To study, investigate and compare the performance of Internal Combustion Engine with and without laser surface texturing ring on the piston.	✓ Referring to all results and observations for an experiment conducted under different operating engine speed with normal piston ring and different patterned laser surface texturing piston ring, it has been found that full width texturing made piston ring reduced the friction power up to 29% as compared with symmetrically at both sides texturing and center portion texturing of 10% and 19% with SAE20W50 lubrication oil and 26 %, 9 % and 15% respectively with SAE20W40 lubrication oil.

✓ To carry out uncertainty analysis of measure quantities/parameters and their effect on the final result.	✓ Uncertainty analysis of measure quantities/parameters has been carried out. And their effect on the final result has been described.

Conclusion

This research provides a comparative study between the un-textured and partial (centered portion and symmetrically both side) and full length textured surface of the piston rings. From the results,

- It is concluded that the frictional losses increase linearly with engine speed.
- It is also observed that there is a significant reduction in friction loss with LST on the piston ring surface compared to the un-textured surface.
- Also, the laser textured piston leads to an effective decrease in the lubrication oil temperatures which can lead to increased life of lubrication oil. Hence it is concluded that there is a definite effect of LST on the engine oil temperature as well.
- It is observed that when engine speed increases, the gradual increase in temperature as the engine speed increased for all three cases.
- The temperature of the cylinder wall remains lower in the case of LST due to the lower friction between the piston and cylinder.
- It has been found that full length texturing made piston ring reduced the friction power up to 29% as compared with symmetrically at both sides texturing and center portion texturing of 10% and 19% with SAE20W50 lubrication oil and 26 %, 9 % and 15% respectively with SAE20W40 lubrication oil..
- These lower frictional losses can result in prolonged life of engine and components. It ensures the smooth running of the engine with better performance and higher thermal efficiency. Brake power is increased by reducing friction power with the help of LST on piston ring in the I.C. engine which indirectly increases the thermal efficiency of I.C.Engine.

Publications

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2. Vijay K. Patel, Bharat M. Ramani, Investigation on Laser Surface Texturing for friction reduction in multi-cylinder Internal Combustion Engine Published in November-2019,

International Journal of Ambient Energy, Taylor Francis Journal

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4. Vijay K. Patel, Bharat M. Ramani, Investigation and performance analysis of three different patterns of Laser surface texturing on piston ring, Communicated in Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, SAGE Publishing.

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