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Review Paper on Experimental Investigation of Partial Laser Surface Texturing on Piston Rings for Reduction of Friction of a Four Stroke Single Cylinder Si Engine Fuelled With Cng

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***Abstract*- Fuel consumption is an extremely important parameter for the automotive industry today. In engines the piston system is the largest source of frictional losses, accounting for about 30% of the total frictional losses, thus it is important to optimize. The lost caused by friction and wear is huge. There is about 30% power of automobile engine lost because of friction, 19% of the power loss is come from the piston ring-cylinder liner pair. This important pair of engine often damaged because of wear. Lubricant film in an internal combustion engine (I.C. Engine) is an important factor in determining fuel economy and performance of the vehicle.**

Keywords- Petrol engine, laser surface texturing, LST, piston ring, Friction.

I. INTRODUCTION

Petrol engine has gained the name and frame in serving the society in many ways. Its main attractions are ruggedness in construction, simplicity in operation and ease of maintenance. But due to friction, we may not be able to avail its services for long time. Hence efforts are being made all over the world, to reducing the friction between the parts in petrol 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. Approximately 50% of the friction losses in an internal combustion engine are due to the piston/cylinder system, of which 70–80% comes from the piston rings.

Proper lubrication and surface texture are key issues in reducing friction in a piston/cylinder system and hence have received great deal of attention in the relevant literature. Surface texturing as a means for enhancing tribological properties of mechanical components is well known for many years. Perhaps the most familiar and earliest commercial application of surface texturing in engines is that of cylinder liner honing. Surface texturing in general and laser surface texturing (LST) in particular has emerged in recent years as a potential new technology to reduce friction in mechanical components.

In this work, the surface micro structure of piston rings is changed by Laser Surface Texturing method, in order to change lubrication regime of surface, and wear resistant. Piston Ring with Fully Textured, Partially textured and the friction data will be compared to base data say Un-textured Piston Rings.

II. LITERATURE REVIEW

Number of research papers and studies has been conducted on the use of Laser Surface Texture and effect of Texturing on Engine Friction and studied the effect of changes in parameters like friction force, texture pattern, viscosity of oil, load capacity etc. Number of reviews has been taken below to complete the present study.

A. Laser Surface Texture on Piston Rings

G. Ryk & I. Etsion (2006) [1] tested piston rings with partial surface texturing. Tests were performed on a reciprocating test rig with actual piston rings and cylinder liner segments. A comparison was made between the performance of a reference non-textured conventional barrel shape rings and optimum partial LST cylindrical shape rings.

The friction tests were carried out with several values of the normal load Fe corresponding to a nominal contact pressure range from 0.1 to 0.3MPa.Typical results are found for a representative case with a nominal contact pressure of 0.2MPa.

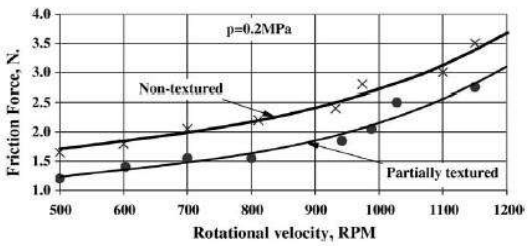

Fig.1. The average friction force vs crank rotational for external normal pressure of 0.2 MPa

The average friction force is presented versus crank rotational velocity for the reference non-textured barrel shape rings and for the partial LST cylindrical face rings. As can be seen the average friction increases with speed and load in both cases as would be expected in a hydrodynamic lubrication regime. Clearly the LST has a substantial effect on friction reduction compared to the non textured reference rings. The average friction obtained with the partial LST cylindrical face rings is about 20–25% lower than in the reference barrel face rings over the entire speed range from 500 to 1200 rpm.
They also concluded that the percentage difference between the average friction in the non-textured and partial LST rings was almost independent of the nominal contact pressure, and slightly decreased with increasing rotational velocity. It should be noted that above 900 rpm the vibrations level of the test rig starts to increase and above 1200 rpm it reaches such a level that prohibited testing in this speed range. Hence, the friction measurements at 1200 rpm can be considered less reliable than at the 500–900 rpm range.

Finally, some real engine tests were performed with partial LST barrel shape rings showing very little friction reduction at low speeds below 2000 rpm. Above 2000 rpm this little benefit of the partial LST vanished completely. It seems that the barrel shape, which presumably was arrived at by trial and error experience over many years, is not a good candidate for partial LST. The crowning of the ring face by itself provides strong hydrodynamic effect that masks the weaker hydrodynamic effect of the surface texturing especially at high speeds. Hence, in the future a more appropriate comparison with firing engine test should be made, similar to the present rig test, between the performance of optimum nontextured barrel shape and optimum partial LST cylindrical shape rings. It was found that the partial LST piston rings exhibited about 25% lower friction.

E.Share & I.Etsion (2009) [2] has evaluated the effect of partially laser surface textured piston rings on the fuel consumption and exhaust gas composition of a compression–ignition I.C. engine. Dynamometer tests were performed with a Ford Transit naturally aspirated 2500 cm3 engine at a wide range of engine speeds under near-half-load conditions.

The effect of the LST as applied to the four top piston rings of the engine was tested by the following procedure: in order to minimize the effect of random environment fluctuations, each set of rings was tested in three different days. At each day, the same sets of engine loads and engine speeds were tested in two different procedures; an engine speed increasing test procedure, and an engine speed decreasing test procedure. Each procedure was repeated three times. At each point the engine was allowed to reach steady state conditions, which were typically attained after 20 min.

A comparison was made between the performance of reference non-textured conventional barrel-shaped rings and optimum partial laser surface texturing (LST) cylindrical-shape rings. It was found that the partial LST piston rings exhibited up to 4% lower fuel consumption, while no traceable change in the exhaust gas composition or smoke level was observed.

Y. Kligerman et al. (2005) [3] developed an analytical model of partial LST flat face piston rings where only a portion of the ring face width is textured. The partial LST is based on a so-called “collective” effect of the dimples that provide an equivalent converging clearance between nominally parallel mating surfaces. The time behavior of the friction force is calculated from the shear stresses in the viscous fluid film and the time dependent clearance. An intensive parametric investigation is performed to identify the main parameters of the problem. The optimum LST parameters such as dimples depth, texture area density, and textured portion of the nominal contact surface of the piston ring are evaluated.

It was found that the friction for the optimum partial LST piston rings is significantly lower than that for the corresponding optimum full LST ring. The difference varies from about 30% reduction for narrow rings to about 55% reduction in wide rings.

Aviram Ronen & Izhak Etsion (2001) [4] examined the piston-cylinder system with laser surface textured piston rings. The authors studied the potential use of piston ring micro-surface structure in the form of spherical segment micro dimples to reduce the friction between rings and cylinder liner where the entire ring surface in contact with the cylinder liner was textured. It was demonstrated that significant hydrodynamic effects can be generated by surface texturing even with nominally parallel mating surfaces. The time variation of the clearance between the piston ring and cylinder liner and the friction force at any given operating conditions were obtained by simultaneously solving the Reynolds equation and a dynamic equation. The main parameters of the problem were identified. These were the area density of the dimples, dimple diameter, and dimple depth. An optimum value of the micro dimple depth over diameter ratio was found, which yields a minimum friction force.

It was found that a friction reduction of 30% and even more is feasible with textured surfaces.

G.Ryk, Y.Kligerman, I.Etsion & A.Shikarenko (2002) [5] Experimental study is presented to evaluate the effect of partial laser surface texturing (LST) on friction reduction in piston rings. In a previous study, 30% friction reduction was obtained with full LST where the full width of the piston ring is textured with a very large number of micro dimples that act individually as micro hydrodynamic bearings. In partial LST, only a portion of the piston-ring width is textured with high dimple density producing a “collective” effect of the dimples that provides an equivalent converging clearance even with nominally parallel mating surfaces.

Experimental results obtained with flat and parallel test specimens with partial LST are presented, confirming a previously published theoretical model and the advantage of partial over full LST. Friction reduction by LST with actual production-crowned piston rings and cylinder liner segments is not straightforward and needs further investigation.

It was found that, within the speed limitation of the test rig, a friction reduction of up to about 25% can be obtained with partial LST compared to full LST. This is an additional improvement over the around 40% friction reduction obtained with the full LST compared to the un-textured case. Some preliminary rig and real engine tests with production piston rings and cylinder liners did not show the same amount of friction reduction. These tests were, however, performed with barrel-shaped piston rings and not with conformal cylindrical rings.

G.Ryk, Y.Kligerman & I.Etsion [6] studied effect of inertia forces, squeeze film action and pressure boundary conditions on the friction force between a Laser textured piston ring and cylinder liner surfaces. Two approaches are presented. The first is based on a complete dynamic force equilibrium that takes into account the inertia forces and the squeeze film effects due to the piston ring mass and radial motion, respectively. The second is based on a quasi-static force equilibrium that neglects inertia and squeeze film effects. The consequence of assuming a constant ambient pressure instead of a realistic time variation pressure boundary condition during the engine cycle is also studied for the first approach. By solving a quasi-static force balance problem in conjunction with a proper curve fitting it is possible to obtain sufficient accurate results for both the instantaneous and the average friction forces and to save computing time. The main disadvantage of this solution is its inability to predict the time variation of the clearance where the sliding velocity diminishes and clearance is maintained due to squeeze film effect.

The maximum value of the clearance is strongly affected by the real time variation of the cylinder pressure during the engine cycle. The minimum value of the clearance is the same as for the constant ambient cylinder pressure case. The instantaneous friction force is much less sensitive to the actual cylinder pressure and the error in the average friction force is less than 15%.

K. Patel, Hiren P. Patel, Hitesh J. Yadav, Prof. V.R. Patel (2013) [7] developed experimental set-up at laboratory scale to measure piston ring assembly friction of multi cylinder 800 CC petrol engine system indirectly by measurement of Friction power consumption under different operating parameters i.e. speed, lubricants, laser surface piston ring, effect of coolant at various locations of piston cylinder system (TDC, BDC) are also observed. In the fabrication of laser surface piston ring assembly friction measurement test rig, 800 CC multi cylinder internal combustion engine system with crank mechanism, piston cylinder head, and engine lubrication system without engine cooling system, without gear box is used. Here crank shaft is coupled with induction motor to drive the engine as shown in fig. 3.3. For varying the speed of test rig, the A.C. motor drive/variable frequency drive is used. To measure the temperature of engine, the temperature sensors are installed at different seven locations and the temperature is indicated by digital value. In the test rig, Variable frequency drive, Digital tachometer, laser radiation pyrometer and the digital indicator to measure the temperature are fitted in a box as shown in fig. 2.

In this experiment Piston Ring with line cross hatch marking fully textured and the friction data will be compared to base data say Un-textured Piston Rings. Here Average percentage of reduction in Friction power is 10.52 % by using Laser surface texturing piston ring.

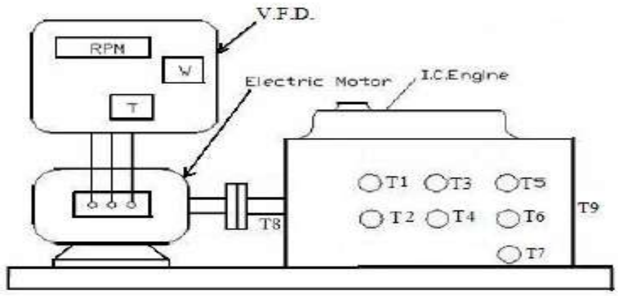

Fig.2. Layout of experimental test rig set-up

B. Laser Surface Texture on cylinder Liner

Staffan Johansson et al. (2010) [8] In their experiment, reciprocating tribometer at Volvo Technology has been updated to better evaluate the frictional difference between material combinations/surfaces; it is possible to evaluate a number of operational parameters in each experiment. The components that were studied were a piston ring running against a cylinder liner. Friction, wear and change in surface morphology were studied in the experiments. It is shown that for the introduced DoE based tribometer test the interaction of dynamic viscosity, velocity and contact pressure can be studied within one experiment. The results show differences in friction which could be explained as the surface creating beneficial contact conditions for oil film build-up. It is also apparent that surface roughness is important regardless of material properties. To better understand the correlations between friction and surface roughness a future study should include a study of similar materials with different roughness values.

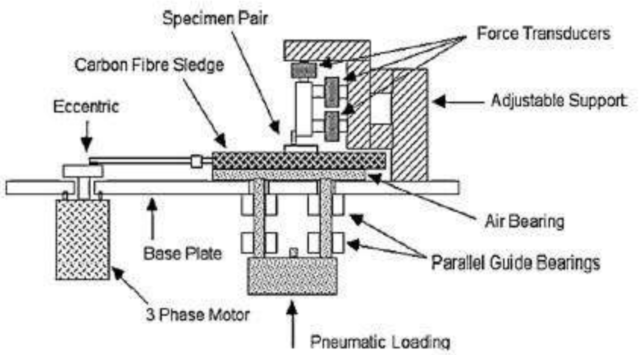

Fig.3. Overview of the reciprocating eccentric tribometer

For the materials studied in this work [Gray cast iron] it is apparent that surface roughness is important in the mild wear situation regardless of material properties, this is accurate for boundary and mixed lubrication regime. It can be clearly seen that all part of the surface amplitude should be minimized to decrease friction; however, due to the multitude of surface roughness parameters that shows a significant correlation to friction it is difficult to draw conclusions of what surface characteristic that is of most importance to decrease friction.

Yuankai Zhou et al. (2012) [9] In their paper, a theoretical model of the load carrying capacity and film thickness for the first compressed ring were developed based on the Reynolds equation and the dynamic operation conditions of cylinder liner and piston ring of CY6102 type diesel engine,. Based on the theoretical models, the effects of the texturing parameters on the load carrying capacity and film thickness were investigated under different velocities, and the ranges of optimum texturing parameters were found. An optimal texturing design method on cylinder liner was proposed. It shows that on cylinder liner, texturing with variable parameters in different velocity ranges can produce higher load carrying capacity and film thickness than that with invariable parameters.

The texturing with variable parameters in different velocity ranges can produce thicker film than the invariable texturing, the same results can be found at the top and bottom dead center, indicating that it is a good method to improve the hydrodynamic lubrication effect than others.

C. Laser Surface Texture On Face Seal

Wan Yi et al. (2007) [10] in their paper, laser was used to generate micro pores on T8 steel surface and the structure and morphology features of surface micro pores were observed. Tribological experiments were conducted with a ring-on-disc tester under various loads and speeds. It is shown that the maximum PV value of face seal can be increased by hydrodynamic effect of micro pores.

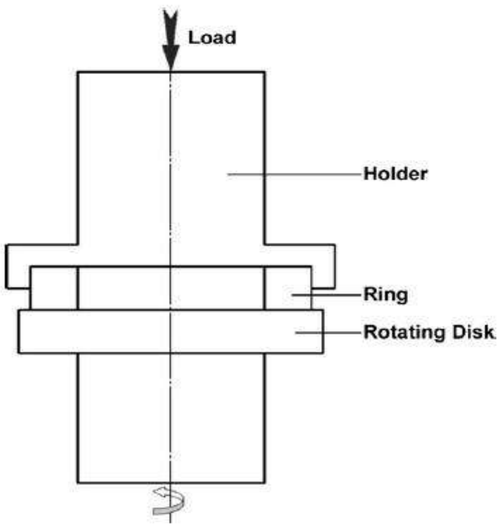

Fig.4. Ring-on-disc friction testing

Frictional properties of laser-micro pored surface were assessed through ring-on-disc tests, simulating a face seal contact interface with different loads and speeds. The findings are concluded as follows:

All the surfaces had similar trends with the friction coefficients decreased at the initial stage and increased gradually with load and speed. Compared with the polished surface, the laser-micropored seal surface can improve the maximum PV value to 2.5 times.

D. Laser Surface Texture effect in soft elastohydrodynamic lubrication

A.Shikarenko et al. (2008) [11] a theoretical model is developed to study the potential use of laser surface texturing (LST) in the form of spherical microdimples for soft elasto-hydrodynamic lubrication (SEHL). The model consists of mutual smooth elastomeric and LST rigid surfaces moving relatively to each other in the presence of viscous lubricant. The pressure distribution in the fluid film and the elastic deformations of the elastomer are obtained from a simultaneous solution of the Reynolds equation and the equation of elasticity for the elastomer. An extensive parametric investigation is performed to identify the main important parameters of the problem, which are the aspect ratio and area density of the dimples. The parametric analysis provides optimum parameters of the surface texturing and shows that LST effectively increases load capacity and reduces friction in SEHL.
It was found that texturing of the rigid counterpart generates a load-carrying capacity that can be maximized by selecting a preferred dimple area density, Sp, and an optimum dimple aspect ratio, e. The optimum parameters for maximum load also minimize the friction force. It was found that the dimple radius does not affect the tribological performance of SEHL. The best value of the dimple are a density, Sp, is almost independent of all the other parameters of the problem and is about Sp=0.3.

The optimum aspect ratio depends exclusively on the SEHL stiffness index, E. As E changes from 420 to 6×105, the optimum aspect ratio (e) opt varies from 0.1 to 0.02, respectively. Further increase of E does not affect the optimum aspect ratio, which remains 0.02.

E. Laser Surface Textured Under Lubrication Initial Point Contact

Andriy Kovalhenko et al. (2010) [12] discussed the effect of laser-textured surfaces on the tribological properties under a point ball-on-flat contact configuration. Tribological experiments were performed with dimpled flats in a pin-on-disk friction machine at speeds from 0.015 to 0.75 m/s using oils with different viscosity. Disks with dimples having different depths and densities were evaluated.
Results showed that disks with higher dimple density produced more abrasive wear on the ball specimen. However, this higher wear rate led to faster generation of conformal contacts and a transition from the boundary to mixed lubrication regime, resulting in a rapid reduction in the friction coefficient with increased ball wear. The wear rate was higher in tests with lower viscosity oils, as

expected. Results of the study may be beneficial for optimization of LST technology for industrial application in friction units.

III. CASE-STUDY

We have taken research work done by G.Ryk & I.Etsion [1] as a Case study. They tested piston rings with partial surface texturing. In this study friction tests were carried out with several values of the normal load Fe corresponding to a nominal contact pressure range from 0.1 to 0.3MPa.

A special test rig was designed to provide linear reciprocating sliding motion simulating the case of piston ring and cylinder liner. The main structural features of the test rig are shown in Fig. 5 An electric motor 1 drives the crank mechanism 2 that ensures reciprocal motion of a cylinder liner segment along the two linear bearing guides 9, fixed on a common basis and isolated from the laboratory floor by special damping pads. A self-alignment holder mechanism 4 ensures alignment of two piston ring segments with respect to the counterpart cylinder liner segment. It also allows the application of a normal load Fe as well as feeding of lubricant to the contact zone and leading out wires of thermocouples that are embedded in the piston ring specimens to measure their face temperature. A special device consisting of two elastic beams 11 was designed to measure the friction force. These beams allow the displacement of an arm 13, which deflects due to the friction force acting between the rubbing surfaces. Strain gauges attached to the elastic beams register the time variations of this deflection corresponding to variations in the friction force between piston rings and cylinder liner. The reciprocating speed measurement is realized with an optical gauge 14.

A schematic of the test is presented in Fig. 2 showing two production piston ring segments 6 and a production cylinder liner segment 7. The angular extent of the contact between ring segments and cylinder liner surfaces is 40 degrees. The ring segments are freely mounted in special grooves in the holder to simulate real piston ring possible tilt during reciprocation.

The operating normal load Fe is applied to the self-aligned specimens' holder by means of accurate weights. Fully formulated engine oil SAE 40 is supplied from a reservoir 1 through a metering system for lubricant flow rate control by drip lubrication. The feeding oil system is used to simulate actual oil. The layout of the setup is shown in the Fig. 1.

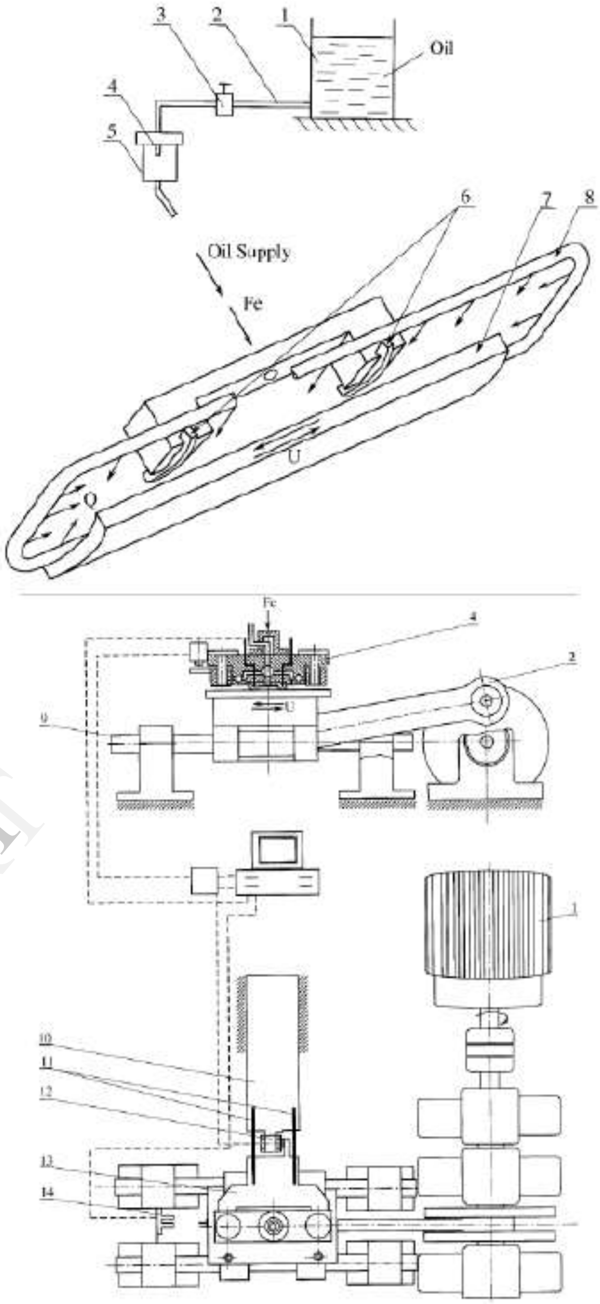

Fig.5. Layout of Experimental setup Test procedure:-

The parameters that could be varied in the present study are:

- operating normal load Fe,
- sliding speed U,
- Ambient temperature,
- Oil feeding rate,
- Parameters of the laser texturing.

The friction tests were carried out with several values of the normal load Fe corresponding to a nominal contact pressure range from 0.1 to 0.3MPa. The lower contact pressure represents typical values caused by the ring's own elasticity in a real engine. The higher contact pressure represents the additional average gas pressure acting on the back of the ring, which for a medium power gasoline engine is about 0.2MPa. It is important to emphasize that the actual external normal load Fe acting on the piston ring varies with time (crank shaft angle) along with the gas pressure change in the combustion chamber. However, since the average friction force is only slightly affected (less than 15%) by the combustion pressure spike, the external normal load in the present experiments was maintained constant during the reciprocation of the specimens.

The average friction force over one reciprocating cycle was evaluated by on-line integration of the absolute values of the instantaneous measured friction force. The resolution of these measurements was 0.1N and the accuracy was 5%. The average friction force was used to evaluate the efficiency of the partial LST.

All tests started at 500 rpm followed by step increments of 100 rpm each, up to the maximum speed of 1200 rpm. It took between 3 and 5 min for the surface temperature to stabilize at each speed level. After reaching the stable temperature, friction measurement was taken at each speed level. A personal computer accomplished data acquisition and processing thus enabling online calculation of the average friction force over one cycle of revolution at every crank speed. The technical specifications of the engine were presented in Table 1.

TABLE I. SPECIFICATIONS OF THE ENGINE

Type	Vertical [TRB]
KW/H.P	5.9 / 8 H.P.
RPM	850
S.F.C	268 gm/kwh
Governing class	B1
Lubrication Oil	SAE 30
Fuel	HSD
Engine No.	9835

IV. RESULTS AND DISCUSSION

Two series of tests were carried out to study the benefit of Partial LST in friction reduction of textured piston rings. The first consisted of the nontextured barrel shape face rings to establish a reference, and the second was performed with partial LST cylindrical face rings.

Typical results are shown in Fig. 6 for a representative case with a nominal contact pressure of 0.2MPa. The average friction force is presented versus crank rotational velocity for the reference nontextured barrel shape rings and for the partial LST cylindrical face rings. As can be seen the average friction increases with speed and load in both cases as would be expected in a hydrodynamic lubrication regime. Clearly the LST has a substantial effect on friction reduction compared to the non textured reference rings. The average friction obtained with the partial LST cylindrical face rings is about 20–25% lower than in the reference barrel face rings over the entire speed range from 500 to 1200 rpm.

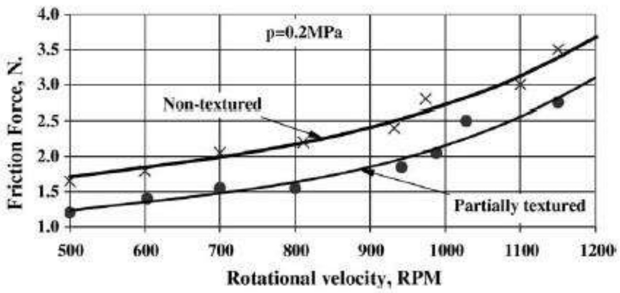

Fig.6. Time average friction force vs. crank rotational velocity for external normal pressures of 0.2MPa.

Very similar behavior of that shown in Fig. was found over the entire range of the tested external normal load. Only the friction level was slightly shifted up or down for higher (0.3MPa) or lower (0.1MPa) nominal contact pressure, respectively. The percentage difference between the average friction in the non textured and partial LST rings was almost independent of the nominal contact pressure, and slightly decreased with increasing rotational velocity. It should be noted that above 900 rpm the vibrations level of the test rig starts to increase and above 1200 rpm it reaches such a level that prohibited testing in this speed range. Hence, the friction measurements at 1200 rpm can be considered less reliable than at the 500–900 rpm range.

Finally, some real engine tests were performed with partial LST barrel shape rings showing very little friction reduction at low speeds below 2000 rpm. Above 2000 rpm this little benefit of the partial LST vanished completely. It seems that the barrel shape, which presumably was arrived at by trial and error experience over many years, is not a good candidate for partial LST.

The crowning of the ring face by itself provides strong hydrodynamic effect that masks the weaker hydrodynamic effect of the surface texturing especially at high speeds. Hence, in the future a more appropriate comparison with firing engine test should be made, similar to the present rig test, between the performance of optimum non-textured barrel shape and optimum partial LST cylindrical shape rings.

V. CONCLUSION

Friction reduction with partial laser surface texturing (LST) cylindrical face piston rings was evaluated on a reciprocating test rig by measuring the friction force between piston rings and cylinder liner segments. The results were compared with a reference non-textured barrel face piston ring. It was found that, within the speed limitation of the test rig, a friction reduction of up to about 25% can be obtained with partial LST cylindrical face rings. Some preliminary real engine tests, with production (barrel shaped) piston rings and cylinder liners did not show the same amount of friction reduction. Further investigation is required with a firing engine using optimum partial LST cylindrical face rings.

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