TRIBOLOGICAL INVESTIGATION WITH TEXTURED PISTON RINGS TO IMPROVE THE PERFORMANCE OF IC ENGINE LUBRICATED WITH FRESH AND SILICATE COMPLEXES NANO-MATERIAL BLENDED OILS

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by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the

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Dedicated to

My daughter late **Teesta Atulkar**

My mother **Smt. Shivali Atulkar**, my father **Shri Bhomya Atulkar,** my wife **Roshani Atulkar**

Certificate

This is to certify that the thesis entitled "**Tribological investigation with textured piston rings to improve the performance of IC engine lubricated with fresh and silicate complexes nano-material blended oils"** being submitted by **Mr. Ashok Atulker** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a record of bonafide work carried out by him under our supervisions. This thesis is in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi. We further certify that the thesis has attained a standard required for the award of degree of Doctor of Philosophy. As per our awareness, the research work and results presented in this thesis have not been submitted, in part or full, to any other institute or university for the award of any other degree or diploma.

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Ashok Atulker

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Abstract

In internal combustion (IC) engines, the piston ring-cylinder liner interface plays a critical role in the efficient engine performance and exhaust emissions. It is an established fact that IC engines are prime emitters of greenhouse gases, which are responsible for environmental issues. The frictional behaviour of the interface of the piston ring/liner is significantly linked to fuel consumption and emissions. Since couple of decades, attempts are being made by the research community to enhance the IC engines performance using various techniques such as design/modification of the thermodynamic cycles, employing light weight components, use of additives/nano materials in the lubricative oils, modification of the surface topography of the piston ring and cylinder liner etc. Since recent past, the surface texture has evolved as a technology that is being used by the investigators across the globe to address the tribological issues of conformal and nonconformal lubricated contacts found in various machines. It has been established that certain surface textures and profiles employed on the piston ring have proven beneficial. Therefore, conducting further research on IC engine performance by conceiving and employing the new surface topography on the piston ring and cylinder liner and blending promising nanomaterials in the lubricant, are vital task.

Hence, the objectives of this thesis were set: (i) mathematical modelling of lubricated interface employing textured top compression piston ring for exploring the friction reduction; (ii) experimental study for IC engine performances using textured top compression piston rings; (iii) performance study of IC engine using silicate complexes ($Mg_6.SiO_{10}.(OH)_8$) nano-material blended lubricating oil; and (iv) synergistic effects of silicate complexes nano-materials blended lubricant and textured top compression piston ring on the performances of IC engine.

Based on the numerical simulations, it is found that the textured piston ring significantly improved the engine performance parameters (increase in minimum oil film thickness and reduction in power-loss) in comparison to the conventional parabolic-shaped piston ring. The textured piston ring led to an increase (up to 7.2%) in the minimum film thickness and an 11% reduction in power-loss as compared to the conventional (un-

textured) piston ring. The textured piston ring yielded overall best performance; however, in the vicinity of the top dead center and in the middle of the strokes, the results were quite favourable. The experimental investigations revealed that the presence of micro-textures on the piston ring reduced the fuel consumption in the range of 2% - 4%, the brake-specific fuel consumption minimized in the range of 4% - 7% and the brake thermal efficiency enhanced up to 7%.

The experimental investigations with the synergistic effect of textured piston ring and nanomaterial blended lubricant showed promising results as the fuel consumption reduced in the range of 1.5% - 4.5%, brake-specific fuel consumption minimized in the range of 4.5%-6.5%, and brake thermal efficiency increased in the range of 5%-7%. In the case of nanomaterial blended lubricant, fuel reduction was observed in the range of 1% - 3%, brake-specific fuel consumption in the range of 1%-5%, and brake thermal efficiency increased in the range of 1%-5%.

Moreover, the CO emission reductions were observed in the range of 7%-10% and HC emission reduction in the range of 3.4%-6.5% with the synergistic effect. On the other hand, HC emission reduction was found in the range of 1.5%-4% in the case of nanomaterial blended engine oil.

सार

आंतरिक दहन (आईसी) इंजनों में, पिस्टन रिंग-सिलेंडर लाइनर इंटरफ़ेस कुशल इंजन प्रदर्शन और निकास उत्सर्जन में महत्वपूर्ण भूमिका निभाता है। यह स्थापित तथ्य है कि आईसी इंजन ग्रीनहाउस गैसों के प्रमुख उत्सर्जक हैं, जो पर्यावरणीय मुद्दों के लिए जिम्मेदार हैं। पिस्टन रिंग/लाइनर के इंटरफेस का घर्षण व्यवहार ईंधन की खपत और उत्सर्जन से महत्वपूर्ण रूप से जुड़ा हुआ है। कुछ दशकों से, अनुसंधान समुदाय द्वारा विभिन्न तकनीकों का उपयोग करके आईसी इंजन के प्रदर्शन को बढ़ाने के प्रयास किए जा रहे हैं जैसे कि थर्मोडायनामिक चक्रों के डिजाइन / संशोधन, हल्के वजन के घटकों को नियोजित करना, स्नेहक तेलों में एडिटिव्स / नैनो सामग्री का उपयोग, संशोधन पिस्टन रिंग और सिलेंडर लाइनर आदि की सतह की स्थलाकृति। हाल के दिनों से, सतह की बनावट एक ऐसी तकनीक के रूप में विकसित हुई है जिसका उपयोग दुनिया भर के जांचकर्ताओं द्वारा विभिन्न मशीनों में पाए जाने वाले अनुरूप और गैर-अनुरूप लुब्रिकेटेड संपर्कों के आदिवासी मुद्दों को संबोधित करने के लिए किया जा रहा है। यह स्थापित किया गया है कि पिस्टन की अंगूठी पर नियोजित कुछ सतह बनावट और प्रोफाइल फायदेमंद साबित हुए हैं। इसलिए, पिस्टन रिंग और सिलेंडर लाइनर पर नई सतह स्थलाकृति की कल्पना और नियोजित करके आईसी इंजन के प्रदर्शन पर और शोध करना और स्नेहक में आशाजनक नैनोमटेरियल्स का सम्मिश्रण करना महत्वपूर्ण कार्य है।

इसलिए, इस थीसिस के उद्देश्य निर्धारित किए गए थे: (i) घर्षण में कमी की खोज के लिए बनावट वाले शीर्ष संपीड़न पिस्टन रिंग को नियोजित करने वाले लुब्रिकेटेड इंटरफ़ेस का गणितीय मॉडलिंग; (ii) टेक्सचर्ड टॉप कम्प्रेशन पिस्टन रिंग्स का उपयोग करके आईसी इंजन के प्रदर्शन के लिए प्रायोगिक अध्ययन; (iii) सिलिकेट कॉम्प्लेक्स ($Mg6.SiO10.(OH)8$) नैनो-सामग्री मिश्रित स्नेहक तेल का उपयोग कर आईसी इंजन का प्रदर्शन अध्ययन; और (iv) आईसी इंजन के प्रदर्शन पर सिलिकेट परिसरों नैनो-सामग्री मिश्रित स्नेहक और बनावट वाले शीर्ष संपीड़न पिस्टन रिंग के सहक्रियात्मक प्रभाव।

संख्यात्मक सिमुलेशन के आधार पर, यह पाया गया है कि बनावट वाली पिस्टन रिंग ने पारंपरिक परवलयिक आकार के पिस्टन रिंग की तुलना में इंजन के प्रदर्शन मापदंडों (न्यूनतम तेल फिल्म की मोटाई में वृद्धि और

बिजली-हानि में कमी) में काफी सुधार किया है। टेक्सचर्ड पिस्टन रिंग ने पारंपरिक (अन-टेक्सचर्ड) पिस्टन रिंग की तुलना में न्यूनतम फिल्म मोटाई में वृद्धि (7.2%) और पावर-लॉस में 11% की कमी की। बनावट वाली पिस्टन रिंग ने समग्र रूप से सर्वश्रेष्ठ प्रदर्शन किया, हालांकि, शीर्ष मृत केंद्र के आसपास और स्ट्रोक के बीच में परिणाम काफी अनुकूल थे। प्रायोगिक जांच से पता चला कि पिस्टन रिंग पर सूक्ष्म बनावट की उपस्थिति ने ईंधन की खपत को 2% - 4% की सीमा में कम कर दिया, ब्रेक-विशिष्ट ईंधन की खपत 4% - 7% की सीमा में कम हो गई, और ब्रेक थर्मल दक्षता 7% तक बढ़ाया गया है।

टेक्सचर्ड पिस्टन रिंग और नैनोमटेरियल ब्लेंडेड लुब्रिकेंट के सहक्रियात्मक प्रभाव के साथ प्रायोगिक जांच ने आशाजनक परिणाम दिखाए क्योंकि ईंधन की खपत 1.5% - 4.5% की सीमा में कम हो गई, ब्रेक विशिष्ट ईंधन की खपत 4.5% -6.5% की सीमा में कम हो गई, और थर्मल दक्षता 5% -7% की सीमा में वृद्धि हुई। नैनोमटेरियल मिश्रित स्नेहक ईंधन की कमी 1% - 3% की सीमा में देखी गई, ब्रेक विशिष्ट ईंधन खपत 1% -5% की सीमा में, और थर्मल दक्षता 1% -5% की सीमा में बढ़ी।

इसके अलावा, सहक्रियात्मक प्रभाव के साथ सीओ उत्सर्जन में कमी 7% -10% और एचसी उत्सर्जन में 3.4% -6.5% की सीमा में कमी देखी गई। दूसरी ओर, नैनोमैटेरियल ब्लेंडेड इंजन ऑयल के मामले में एचसी उत्सर्जन में कमी 1.5% -4% की सीमा में पाई गई।

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Nomenclature

F	Viscous friction, N
F_a	Boundary friction, N
h	Film thickness in the y-direction, m
h_m	Minimum film thickness, m
h_p	Ring's profile
i, j	Indices of grid points
L	Ring length in the axial direction, m
l	Crown offset from the center
l_c	Connecting rod length, m
m	Grids in the axial direction
N	Iteration number
n	Grids in the circumferential direction
P	Hydrodynamic pressure, Pa
p	Contact pressure, Pa

P_c	Cavitation pressure, Pa
P_{el}	Ring elastic pressure, Pa
P_L	Pressure below piston ring, Pa
P_T	Combustion gas pressure, Pa
P_t	Pitch distance, m
r_s	Dimple radius, m
r_t	Dimple depth, m
W_p	Power-loss, Watt
W_{pa}	Average Power-loss, Watt
W_T	Total backpressure, Pa
$W(t)$	Load carrying capacity, N/m
x,y,z	Cartesian coordinates
x_c , z_c	Center points of a circular texture
x_{cav}	The distance at which cavitation starts, m
z_1	Circumferential length in the z-direction, m

Greek symbols

ρ	Lubricant density, kg/m^3
σ	Composite roughness, rpm
α	Pressure viscosity coefficient
β	Bulk modulus, Pa
ϕ	Lubricant film content
ω	The rotational speed of the crank, rpm
λ	Ratio of crank radius over connecting rod length
θ	Crank angle, rad
r_c	Friction coefficient
η	Lubricant's dynamic viscosity, Pa-s
η_0	Atmospheric viscosity
ε_p	Convergence criteria
Ω	The area occupied by textures, m^2
$\wedge$	Ratio of the film thickness to the composite surface roughness

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