Study of Friction Characteristics of a Diesel Engine running on different Viscosity grade Engine Oils using Conventional and Acoustic Emissions Technique

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ABSTRACT

Experimental studies were conducted on an off-highway heavy duty diesel engine running on different viscosity grade engine oil, for determining the friction power in a firing engine by measuring the indicated mean effective pressure (IMEP) by in–cylinder pressure sensor and calculating the Indicated power and Brake power. It is known fact that hydrodynamic friction is related to the viscosity of engine oil and it has been shown that this friction can be reduced by using low viscosity grade engine oil [1]. Experimental results of friction power are compared with the novel use of non-intrusive acoustic emission (AE) technique to provide information pertaining to engine friction. Conventional method of friction assessment revealed that there is some improvement in reducing engine friction power when lower viscosity grade engine oil is used in place of recommended grade viscosity oil. These findings were corroborated with the modern AE technique which also indicated the benefits of using lower viscosity grade engine oil in reducing the friction. This paper will extend the scope of AE technique for analyzing friction of an engine and may provide an opportunity for in-service monitoring of efficient engine operation.

INTRODUCTION

The critical engine components resulting in the majority of engine friction are; piston ring/liner assembly, bearing system valve train system, and engine powered auxiliaries (such as the water pump, oil pump, fuel pump etc). Two-thirds of the friction losses in an engine are estimated to occur during hydrodynamic lubrication (piston ring/liner assembly, bearings) and one-third during boundary lubrication or mixed lubrication. The new energy-conserving engine oils are designed to reduce friction losses from both types of lubrication by tailoring the viscosity characteristics of the base oil and the chemistry of the friction-modifying additives.

Analysis of piston rings friction in internal combustion engines has been a topic of research for many years. Piston rings act as sealing between the liner and the piston by making thin oil film during their operation. Furuhama [2] incorporated, for the first time the squeeze film effect in the Reynolds equation for analyzing hydrodynamic lubrication for piston ring/liner assembly under fully flooded inlet conditions. Wakuri et al. [3] also analyzed the piston ring assembly by considering the cavitation effect and a squeeze film in the Reynolds equation. However in reality, ring packs do operate under starved condition for some time during its

operation. Starved ring lubrication was also studied by many researchers [4-6] with different boundary conditions. There is a vast literature available regarding piston ring lubrication. Some of the recent works of Mufti et.al [7, 8] on predicting piston ring assembly friction loss in firing engine using the indicated mean effective pressure (IMEP) method and validating the model by experimental study is remarkable.
Acoustic emissions (AE) is a well known and an important tool for condition monitoring and fault diagnosis of interacting surfaces, rotary equipments and others applications. The application of AE for injector performance of a diesel engine was done by Gill J.D [9] et al. Application of AE for exhaust valve leakage of marine diesel engine [10] was also undertaken. AE monitoring provides the pragmatic way of measuring this acoustic emission in the upper frequency ranges beyond vibration and ultrasound. R.M. Douglas et al. [11] studied the piston ring /liner friction in a motored diesel engine and also friction of a 2-stroke marine diesel engine by using the AE technique.
The focus of this paper is to understand the effect of engine lubricant viscosity on friction characteristics of a diesel engine. Engine friction was investigated in terms of friction mean effective pressure (FMEP) of a firing engine, at different engine operating conditions with special emphasis on the particular condition of high speed, low load under controlled conditions to simulate hydrodynamic lubrication conditions. Friction power was evaluated by measuring the in-cylinder pressure, IMEP and calculating Indicated power from it. The acoustic emissions generating from a normal engine operation may be due to different sources such as valve activity, injectors and other processes. Results of these friction characteristics are compared with the with acoustic emission (AE) signals, specifically continuous types, emerging out of engine cylinder. But in this paper, scope of AE technique for understanding the engine friction has been explored.

EXPERIMETAL DETAILS

TEST ENGINE

Engine test to predict the friction mean effective pressure was conducted in the four stroke, four-Cylinder, direct injection heavy duty off-road diesel engine. Specification of the test engine, used for the study is given in the Table 1.

Table 1: Test engine specifications

1.	Engine type	Off-Highway, DI Diesel Engine, Turbocharged
2.	Displacement	4399 cc
3.	Compression Ratio	18.3:1
4.	No. of Cylinders	4
5.	Maximum Power Output	74.2 kw @ 2200 rpm
6.	Torque	385 N-m @1300 rpm

TEST ENGINE LUBRICANTS

Test engine lubricants used in the experimental study are as follows;

Oil ‘A’ SAE 20W-50

Oil ‘B’ SAE 10W-30

Both engine lubricants are commercially available, complying with API CG-4 performance category level. It is to be noted that engine oil ‘A’ was taken as baseline engine lubricant for friction studies.

ENGINE TEST BENCH DETAILS

Test engine coupled with the appropriate AC dynamometer and instrumented with fuel consumption measurement unit, pressure sensor, angle encoder, speed sensor, temperature indicators etc, was used for the study. Engine tests were conducted at two speeds and four loads for each engine lubricant, details of operating condition are given in Table 2. Pressures at each operating speed and load was recorded and IMEP for each operating condition was computed by using a Matlab programme. Friction power (FP) is then calculated by subtracting Brake power (BP) from Indicated power (IP), at each operating point for both oils

Table 2. Engine test operating conditions

Operating Conditions	**Values**
Speed (rpm)	1000 and 2000
Torque (Nm)	50, 100, 200, 300
Temperature oil (^oC)	90 ± 5
Temperature Coolant (^oC)	85-90

PRESSURE SENSOR

In-cylinder combustion pressure was measured by a Kistler type 6125A piezoelectric pressure sensor. The sensor was fixed in the combustion chamber of cylinder number one. The sensor is made of polystable quartz elements, and ground insulated to avoid electrical interferences due to ground loops, it does not require additional cooling. It has also been specially designed to work at high temperatures and for precision measurement of pressure of an internal combustion engines. Table 3 summarizes the brief specifications of the pressure sensor.

Table 3. Pressure sensor specifications

S.No.	**Parameter**	**Value**
1	Pressure range	0 – 25 MPa
2	Sensitivity	-15.8pC/bar
3	Linear error	±0.2FSO
4	Temperature range	-50^oC upto 350^oC

AE SENSOR AND DATA ACQUISITION SYSTEM

The acoustic emission signals were measured using a Wideband sensor model WD as shown in Table 4. This type of sensor made by Physical Acoustics Corporation and has a differential output to decrease the influence of noise. The Wideband sensor includes the frequency range of most of engine events. Acoustic emission sensor has been used for the acquisition of the acoustic emission signal. The AE sensor was mounted near the TDC of third cylinder of the engine to collect the AE signals generated during the operation of engine. To get good signal conductivity, vacuum grease was used to couple the AE sensor with the measurement surface. One of the data streaming technology available for AE data acquisition is the PCI-2 board, provided by Physical Acoustics Cooperation. This board is connected to a computer through the industry standard high-speed (138MB/sec) PCI bus and the sampled AE waveforms can be continuously transferred to the hard disk. Hence the AE signal can be saved as long as the capacity of the hard disk in the computer. The AE measurement system developed in this research is based on the PAC PCI-2 card, which is specially designed for the high-speed data acquisition of AE signals. The AE sensor converts the AE signal to an electrical signal and sends it to the pre-amplifier.

Table 4. Acoustic Emission sensor details

S.NO	**Parameters**	**Value**
1	Operating frequency range	100-1000 KHz
2	Peak sensitivity	55^{+} V(m/s)(dB)
3	Operating temperature	-65 to 177^{o}C
4	Dimensions (dia X ht) mm	18X17

Methodology for conducting experiment test engine was tuned as per the OEM's recommendations before start of the test.

- Engine oil was drained and flushed to remove the surface active chemistry of the previous oil.
- Indicated mean effective pressure (IMEP) measurements was done for calculating the FMEP and also friction power at all the test operating conditions mentioned above.
- AE signals were also taken at each test operating points.
- Engine oil and coolant temperatures were controlled within the range of 90^{o}C ± 5 and 85-90 respectively at all test points
- Initially the baseline engine oil 'A' was charged into an engine for its test run and then oil 'B' was used for the study. For each oil new oil filter was used
- Brake specific fuel consumption (bsfc) was calculated at each test operating point.

RESULTS AND DISCUSSIONS

Test results of the experiments, conducted on both engine oils, were analyzed for Indicated power (IP), Brake power (BP) and Friction power (FP) of an engine at various test operating conditions mentioned above. Calculated values of IP, BP and FP for both oils at different operating conditions are given in Table 5. It has been observed from the friction results that, there is significant rise in engine friction with the increase in engine speed (rpm) at all load points, which indicates that speed is one of the most important factors for engine friction. Other parameters on which engine friction depend are engine load, oil viscosity, oil temperatures etc. Since the oil temperature was controlled (90±5^{o}C) for both engine lubricants, hence the effect of engine lubricant temperature on friction can be ignored.

Table 5. Indicated power (IP), Brake power (BP) and Friction power (FP) for both oils under prescribed engine operating conditions

Speed rpm	**Torque Nm**	**IP (kW)**		**BP (kW)**		**FP (kW)**	
		Oil A	**Oil B**	**Oil A**	**Oil B**	**Oil A**	**Oil B**
1000	50	7.31	7.76	5.22	5.24	2.09	2.52
1000	100	11.78	12.38	10.46	10.51	1.32	1.87
1000	200	22.75	22.87	20.91	20.96	1.84	1.91
1000	300	34.58	34.24	31.42	31.41	3.16	2.83
2000	50	20.89	20.44	10.55	10.49	10.34	9.95
2000	100	31.48	31.12	20.98	20.94	10.50	10.18
2000	200	50.60	48.85	41.78	41.83	8.83	7.02
2000	300	68.81	68.20	62.83	62.95	5.98	5.25

At high speed and low load, simulating the hydrodynamic lubrication conditions, engine friction power is significantly higher as compared to the low speed and low load because piston ring assembly and bearings are predominantly operating in hydrodynamic lubrication regime at high engine speed and low load. And we have already proved that, there is strong dependence of hydrodynamic friction on engine speed and oil viscosity. This strengthens the fact that the percentage contribution of hydrodynamic friction in an engine is higher as compared to the boundary and mixed lubrication friction. At low speed, for all load levels (engine operating in boundary and mixed lubrication regime), it is observed that there is marginal change in engine friction for both oils. AE signals acquired during engine operations at low speed represented in Fig 2 and 3, indicated that higher viscosity grade oil performed comparatively well against the low viscosity grade oil, at all load points.

At high speed, high load the friction power is reduced to a level comparable to the low speed, high load condition; this may be explained with the help of well known fact that the contribution of friction as a percentage of indicated power output reduces as load increases, which is also indicated in Fig 1. It may also be deciphered that shearing of the oil film's sub-layers would be easier at high speed and high load which helps in friction reduction, emanated due to shearing resistance in hydrodynamic lubrication conditions.

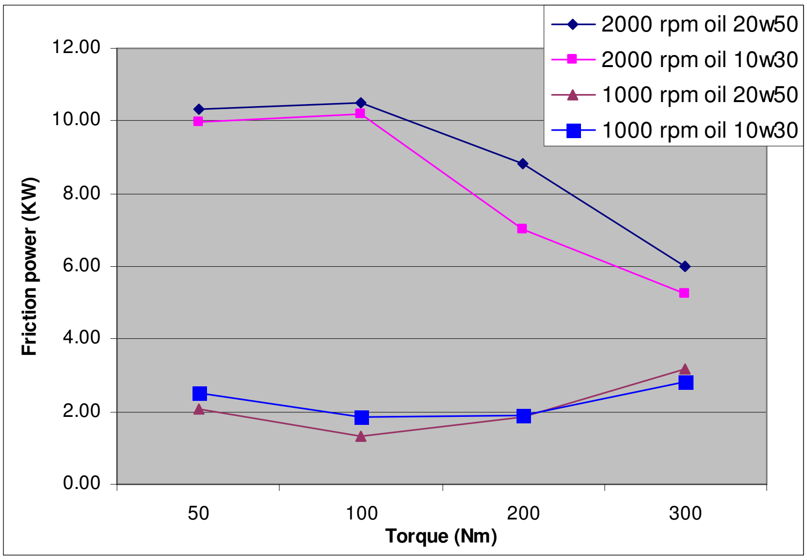

Fig 1. Engine friction power at different operating conditions for both oils

Brake specific fuel consumption (bsfc) at speed of 2000 rpm at all load point of an engine for both engine lubricants were calculated. Tabulated bsfc in (g/kW.hr) is shown in Table 6, percentage reduction in bsfc with the use of lower viscosity grade lubricant was also calculated. Results indicated that, there is significant reduction of fuel consumption of an engine when lower viscosity grade oil was used. Similar trends were observed for gasoline test vehicle during the chassis dynamometer study [12]

Table 6. Percentage reduction of bsfc (g/kW/hr) of an engine operating at 2000 rpm

Torque (Nm)	**bsfc (g/kW.hr)**		**% Reduction**
	Oil A	**Oil B**	
50	372.27	367.30	1.33
100	275.22	269.74	1.99
200	259.26	256.65	1.01
300	234.04	231.46	1.10

ACOUSTIC EMISSION RESUTS

AE signal, both burst and continuous type, comparisons in the angular domain for both oils are shown in the Fig 2. Small difference in peaks for both oils can be seen in the enlarged view of third cylinder of an engine shown in Fig 3. It is observed that at low speed, for all load points, Oil B is having slightly higher peaks, which indicates that there is more asperity contact between piston ring and liner when engine was operating on lower viscosity grade oil at low speed.

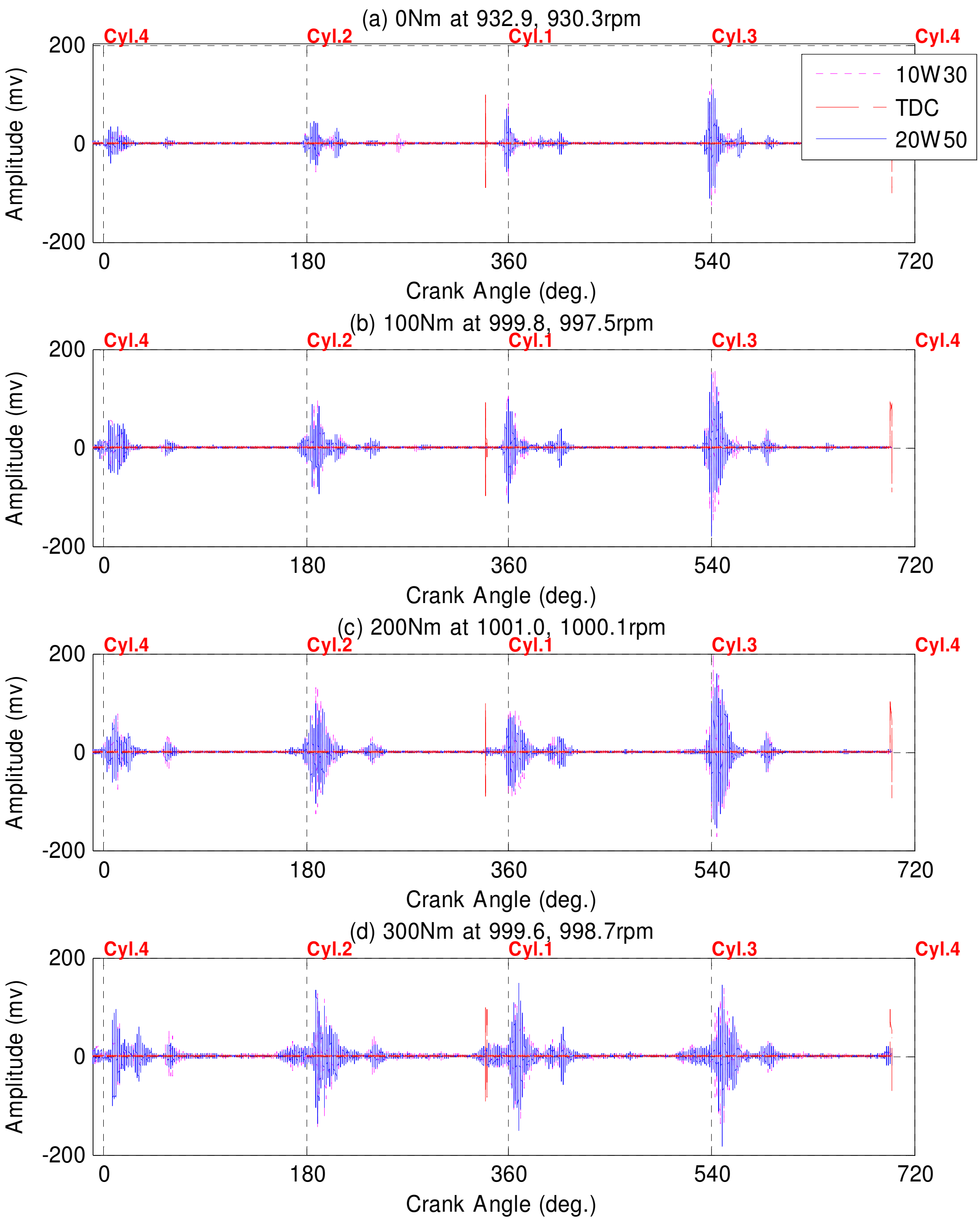

Fig 2. AE signals acquired for both oils during engine operation

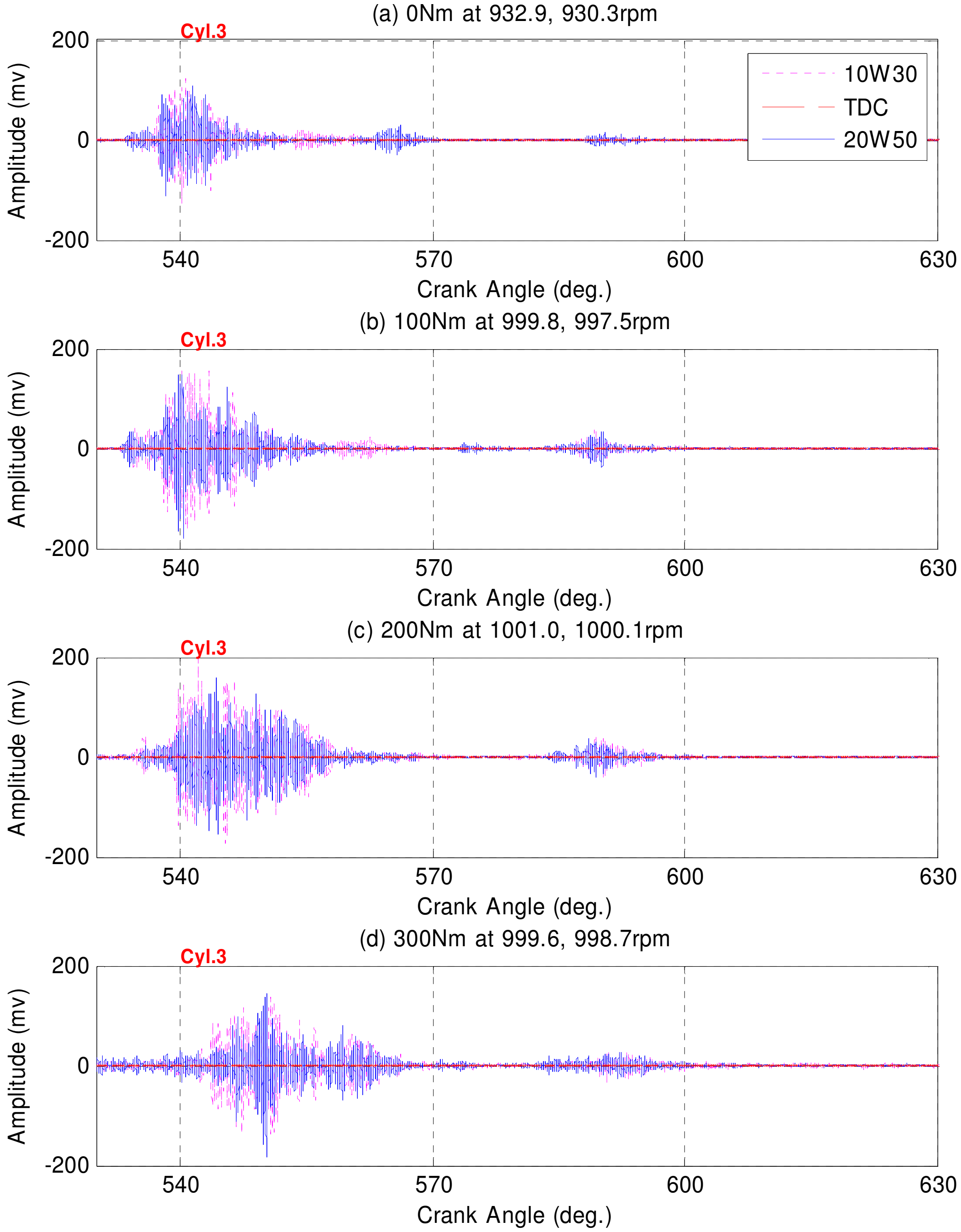

Fig 3. Enlarged view of AE signals cylinder 3

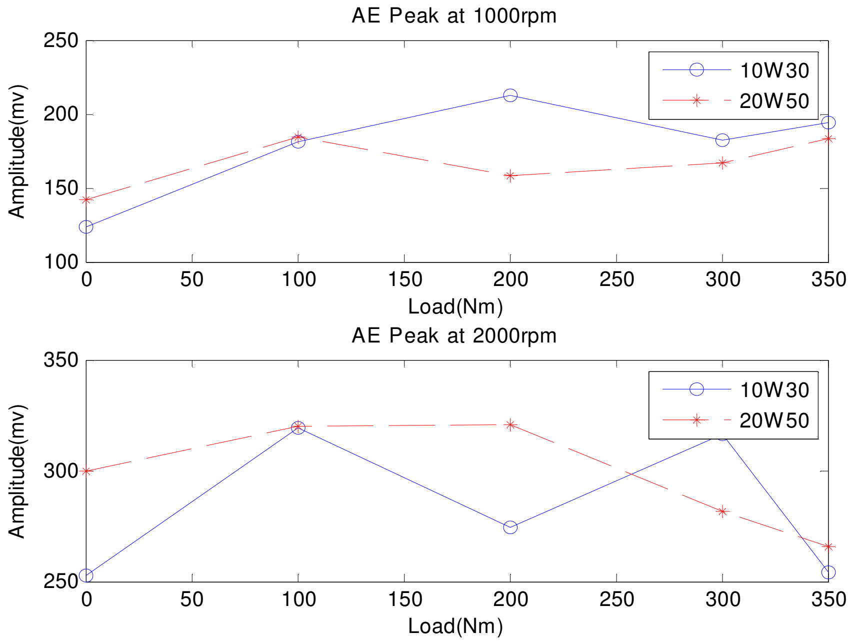

Fig 4 AE peak values at both speed

It can be seen from the Fig 4 that at high speed peak values of oil B are less than the oil A, which also signifies the low friction with low viscosity grade oil. But it has been felt that more advanced signal processing is needed to extract these small differences.

CONCLUSION

Present study investigated the engine hydrodynamic friction theoretically and experimentally. Special emphasis was given on the engine lubricant viscosity's effect on friction power and fuel consumption of an off-road diesel engine. Following points may be summarized from this limited experimental study;

- Engine hydrodynamic friction force is strongly dependent on the engine speed and engine oil viscosity
- There is marginal change in engine friction at lower speed for both oils, higher viscosity grade oil performed well at low speed for all load points. Which strengthen the fact that oil viscosity effect is insignificant at low speed (operating in boundary and mixed lubrication regime)
- Engine friction power can be reduced by using the lower viscosity grade oil at high speed and at all load points without affecting the engine adversely. This is also corroborated by the bsfc results, which showed fuel saving of approximately 2%
- Application of AE technique for analyzing the engine friction was explored in this experimental study, which broaden the scope for in-service monitoring of efficient engine operation.

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