RESEARCH PAPER | Engineering | Volume : 5 | Issue : 8 | August 2015 | ISSN - 2249-555X

Reduction of Turbolag Using Battery Assisted Blower

KEYWORDS: Turbocharger; Turbo Lag; Blower; Inverter; Acceleration Test; Load Test

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ABSTRACT
The project investigates improvements in the turbocharged diesel engine transient response that are possible when a turbocharger power assist system consisting of an electric blower and a inverter coupled to the turbocharger. The method of investigation relies on comparison with a conventional turbocharged diesel engine which reveals the mechanism by which acceleration is boosted while maintaining approximately same fuel efficiency.

1.INTRODUCTION

One of the major challenges faced by the automobile industry is the turbo lag in diesel engines. A turbocharger is a turbine-driven forced induction device that increases an engine's efficiency and power by forcing extra air into the combustion chamber. This improvement over a naturally aspirated engine's output results in more air and proportionately more fuel into the combustion chamber than atmosphere pressure alone.

Turbo lag is the delay in the activation of the turbocharger after the throttle is applied. This delay is due to the time needed by the exhaust system and the turbocharger to generate sufficient boost. Inertia, friction and compressor load are the primary contributors to turbo lag.

There are several methods adopted to eliminate turbo lag in diesel engines. Some of the methods are variable geometry turbochargers, twin-scroll turbochargers, and triple turbo.

The aim of the project to was to reduce the turbo lag in existing vehicles. Most of the modern vehicles have comparatively less turbo lag. So it was required to conduct the experiment on existing vehicles. For the experiment to be a success, it was decided to choose a vehicle with comparatively larger turbo lag. The options that came forward were TATA SAFARI, FIAT SIENA and TATA INDICA. The TATA SAFARI was the first indigenously developed Indian SUV and has comparatively more turbo lag. Any small difference in the activation of the turbocharger will be greatly reflected . So the experiment was decided to be conducted on the TATA SAFARI's engine.

In search of a method for eliminating turbo lag, the idea of using a blower was suggested. The blower was used to supply an additional amount of air into the entry of the turbo pipe. The turbo pipe was bypassed and the air from the blower was supplied through that pipe.

Most of the cars in India are manufactured with parabolic roof tops which act as good solar collectors and are not utilized. So we can place these solar panels in these rooftops which will be very effective in collecting the rays from the sun.

2.THEORY

Several methods are being followed to reduce the turbo lag in diesel engines.

The main objective is to increase the impeller speed of the turbo by an external drive so as to reach sufficient impeller rpm in order to reduce turbo lag.

First method involved coupling a motor to impeller shaft of the turbocharger by extending the turbo shaft. One of the drawbacks of this method was the insufficient speed of the motor.

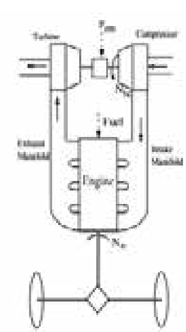

Figure 1: Schematic representation of a diesel engine with a turbocharger power assist system.

Fig 2.1 Schematic diagram of turbocharger power assist

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The only solution to that was the use of a planetary gear system, so that we could obtain the sufficient speed. After reaching sufficient speed the motor should be decoupled otherwise due to very high speed the motor coils will get damaged. But practically this method was found to be complicated and apart from this in order to couple the motor we need to extend the shaft from the turbo which leads to turbo unbalancing.

From further studies it was found that the impeller speed could be increased by using the compressed air from an air compressor. In this method there is no need for extending the turbo shaft, here the compressor can be coupled with the help of flexible pipe. This could be made effective by placing a nozzle near to the impeller blades in such a position that the velocity of the compressed air will rotate the blades and the sufficient speed could be achieved earlier. Since turbo blade is of axial type, nozzle should be designed in such a way that it should be placed in front of the turbo for effective rotation of the impeller blades. But this can lead to the disturbance and obstruction to the flow of the air from the air filter and also the addition of compressor to the engine will make the assembly bulky.

Finally the compressor was substituted with a blower, which overcomes the problem of bulkiness. A variable speed type blower was used.

The blower nozzle assembly is placed in front of the impeller. This is done by making a hole on turbo-inlet pipe as shown in the fig.2.5. Firstly the blower was connected without any nozzle but it lead to obstruction, so the blower output was connected at a short distance from impeller fan using a pipe. But the design of the impeller blade reflected back 80% of the air from the blower and blocked the inlet air passage.

Fig 2.5 Turbo inlet connected to blower

Then an attempt was made by reducing the blower speed and still there wasn't sufficient air to rotate the impeller blade. Hence the position of the blower was changed and was placed at the inlet of the turbocharger pipe. This is done by splitting the air passage by using a splitter made of PVC pipe on which, one side is connected to air filter and other from blower as shown in the fig. This increased the turbo speed by acting as boost to the already passing air from air filter. And we could notice the engines performance getting altered by a wide margin.

Calculation

1. Maximum Load Calculation ()

Brake Power (BP) $=T\omega$,

$\omega=\frac{2\pi N}{60}$ $\quad T=(W_{Max})gr$

N -rated rpm

g -acceleration due to gravity = $9.81 m/s^2$

r -brake drum radius = 32cm

$BP=\frac{(W_{Max})gr2\pi N}{60*1000}$

Now $W_{Max}=\frac{BP*60*1000}{gr2\pi N}$

2. Brake Power (BP)

Brake Power (BP) $=T\omega$, in kW

$T=(W_{Max})gr$

$\omega=\frac{2\pi N}{60}$

$BP=\frac{(W_{Max})gr2\pi N}{60*1000}$

3. Total Fuel Consumption (TFC)

$TFC=\frac{m_f}{t}$ in kg/hr

Mass of fuel, $m_f=\frac{\rho_f v_f}{1000}$

ρ_f =Density of diesel=.82g/cc

v_f =volume of fuel consumption=20cc

t= Average time for v_f volume fuel consumption in seconds= $(t_1+t_2)/2$

t_1= time for v_f volume fuel consumption in seconds

t_2= time for v_f volume fuel consumption in seconds

$TFC=\frac{\rho_f v_f*3600}{1000*t}$

4. Specific Fuel Consumption (SFC)

SFC = TFC/BP in kg/kWhr

TFC in kg/hr

BP in kW

5. Indicated Power (IP)

IP=BP+FP

FP calculated by Willan's Line method

6. Brake Thermal Efficiency (η_{Bth})

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$$\eta_{Bth} = \frac{BP*3600}{TFC*CV}*100\%$$

BP in kW

TFC in kg/hr

CV = Calorific Value of diesel = 42000 kj/hr

7. Indicated Thermal Efficiency (η_{Ith})

$$\eta_{Ith} = \frac{IP*3600}{TFC*CV}*100\%$$

IP in kW

TFC in kg/hr

CV =Calorific Value of diesel=42000kj/hr

8. Mechanical efficiency (η_{mech})

η_{mech} = (BP/IP)*100
BP in kW
IP in kW

4.EXPERIMENTAL TEST SET-UP
TEST-RIG

The frame work for our test rig is made by using cast iron C channel section. The dimension of the C channel is 4"x3". The base for the engine has been set up as per the mounting provided on the engine. The engine is mounted on frame by means of genuine rubber bushing, which is used in TATA SAFARI. For the reduction of vibration, we provide an extra support below the bell housing cover of the engine with the help of engine bushing of HM. By using these bushing the vibration is reduced to a large extent. The welding we used here is arc welding for obtaining rigid structure.

After mounting the engine on the frame, Three C frames are welded to the base of the rig. These C –frames are used to support the fly wheel and the pulley. On these frames supports are provided to hold the stay bearing which is used to balance the engine shaft.

The shaft is fixed to the engine by means of clutch for smooth transmission of torque and to avoid failure of the weld in between the shaft and the engine direct gear. The shaft is welded directly to the direct gear which is connected to engine through splines.

Fig 4.4 Direct gear

During starting and loading there will be a pitch movement for the engine. To accommodate this movement we provide a universal joint between the direct gear and shaft. The universal joint used here is Hook's Joint. The universal can transmit the power up to an angle of 45^0.

The electrical connections were also done on engines so as to provide supply to the alternator, fuel injector and starter motor. Starting of the engine is done by a starting switch and similarly it is turned off by means of a switch. An inverter is also connected to battery to supply power for the blower.

The diesel is stored in a measuring jar which is placed at a certain height so that it flows due to gravity and is fed to the engine through a flexible tube.

Fig 4.7 Test rig.

5.EXPERIMENTAL PROCEDURE

To understand the engine performance acceleration test has been conducted on the engine. Acceleration test is conducted without and with the blower unit which is connected to the engine. In the test we measured the time taken by the engine to reach 3000 rpm from 1000 rpm (idling rpm).

We also performed the load test on the engine with and without the blower unit for plotting the points in the performance graph. For the load test 2500 rpm was taken as the rated rpm. From calculation for the maximum load, 180kg was the obtained value. A factor of safety of 4.5 was selected, and the maximum load became 40kg.

An inverter is used to run the blower from engine battery which converts 12V, 80A to 230V, 600W. We used a variable speed blower so as to study effect various air flow rate on engine performance. For our experiment we set the blower speed regulator position at "2", because from the experiments conducted for variable fan velocity, we noticed that for blower speed above "2" the air will be forced back to the surroundings through air filter due and for blower speed less than "2" the effect of blower is found to be negligible.

Engine Specifications of Safari 2.0 TD LX

Engine type	Turbocharged diesel
Engine code	483 DL
Cylinders	Straight 4
Capacity	1.9 litre / 1948cc
Bore x Stroke	83 x 90 mm 3.27 x 3.54 in
Bore/stroke ratio	0.92
Engine properties	Single overhead camshaft (SOHC) 2 valves per cylinder 8 valves in total

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Max engine power	90ps / 89bhp / 66kW @ 4300 rpm
Specific output	45.7 bhp/litre
Max torque	190 Nm at 2000-3000 rpm
Specific torque	97.54 Nm/litre
Bmep (brake mean effective pressure)	1225.7kPa
Engine coolant	Water
Unitary capacity	487 cc
Aspiration Turbo D	Y
Intercooler	Y
Catalytic converter	Y
Power-to-weight ratio	34.57 kW/g

TABLE 5. 1 Engine Specification

Specification of blower:

- Powerful 600 W motor.
- Air flow of 3.3 cubic meter per min for powerful cleaning performance.
- Variable speed control provides extra versatility in different applications.
- Maximum speed 16000 rpm.

PROCEDURE FOR ACCELERATION TEST

- ***Connect the engine to the battery source; ensure that the connections are on corresponding positive and negative terminals. An inverter is also connected to the battery.***
- Fill the fuel tank with diesel; connect the hose from the return valve back to fuel tank to collect the diesel from it.
- Ensure that the passage of the air blower is kept closed for performing the test without blower.
- Disengage the clutch before starting the engine.
- Open the valve of the fuel tank.
- Switch ON the heater plug for few seconds for primary heating.
- Push the button to start the engine, by applying throttle.
- Engage the clutch lever for transmitting power to the shaft.
- Apply load using the belt, by tightening the screw provided.
- Provide adequate cooling to pulley, since it gets heated up quickly.
- Apply a specific load.
- After loading the engine bring the engine to idling state.
- Then the engine is accelerated quickly from idling rpm to 3000 rpm.
- Note down the time taken to reach idling 3000 rpm from idling with the help of a stop watch.
- Likewise this test is carried out on different load like No load, 10kg, 20kg, 30kg and 40kg.
- After completing the test without blower, remove the stopper on the air passage and connect blower output to that passage.
- Connect the terminals of the blower to the inverter.
- Ensure that the speed regulator of the blower is in "2" position.
- Repeat the steps from 10 to 15.

PROCEDURE FOR LOAD TEST

- Connect the engine to the battery source; make ensure that the connections are on appropriate terminals. An inverter is also connected to the battery.
- Fill the fuel tank with diesel. Connect the fuel tank to a measuring jar and connect the pipe from the return valve back to measuring jar.
- Ensure that the passage for the air blower is kept closed for performing the test without blower.
- Ensure that the clutch is in disengaged position
- Open the valve on the fuel tank.
- Heat the heating plug by switch ON the switch for heating plug.
- Switch OFF the heater switch.
- Push the button to start the engine, by applying throttle.
- Engage the clutch lever for transmitting power to the shaft.
- Apply load by using belt, by tightening the screw provided.
- Provide adequate cooling to pulley, since it get heated up quickly.
- Apply a specific load.
- Run the engine at 2500 rpm.
- Measure time taken to consume 20cc of fuel with the help of stop watch.
- Likewise this test is carried out on different load like No load, 10kg, 20kg, 30kg and 40kg.
- After completing the test without blower, remove the stopper on the air passage and connect blower output to that passage.
- Connect the terminals of the blower to the inverter.
- Ensure that speed regulator of the blower is in "2" position.
- Repeat the steps from 10 to 15.

6.RESULT AND DISCUSSION

Test was conducted on the engine for four different loading conditions which are referred to as cases 1-5 as summarized in table 1.

CASE	LOAD (kg)	SPEED (RPM)	TIME TAKEN FOR REACHING 3000rpm,(without blower) (s)	TIME TAKEN FOR REACHING 3000rpm,(with blower) (s)
1	0	1000-1500 2000 2500 3000	0.49 0.99 1.25 1.97	.48 1.005 1.305 1.938
2	10	1000-1500 2000 2500 3000	0.635 1.055 1.595 2.175	0.555 1.01 1.385 2.16

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3	20	1000-1500 2000 2500 3000	0.65 1.04 1.65 2.62	0.40 1.03 1.335 2.43
4	30	1000-1500 2000 2500 3000	1.005 1.455 1.96 2.755	0.55 1.173 1.886 2.64
5	40	1000-1500 2000 2500 3000	1.11 1.825 2.82 5.51	0.49 0.99 1.39 2.14

TABLE 6. 1 Result of acceleration test

Speed v/s time graphs are plotted for no load, 10kg,20kg,30kg,40kg, when connected to blower and also when not connected with blower.

Load test without blower

Load (kg)	BP (KW)	TFC (kg/h)	SFC (kg/KW)	Break thermal efficiency, (%)	Indicated power,IP (KW)	Mechanical efficiency (%)	Indicated thermal efficiency (%)
0	0	1.798	∞	0	12.4	0	59.11
10	4.109	2.394	0.583	14.70	16.509	24.89	59.108
20	8.128	2.785	0.339	25.28	20.618	39.85	63.456
30	12.328	3.602	0.292	29.35	24.728	49.85	58.843
40	16.437	3.779	0.229	37.43	28.837	56.99	65.407

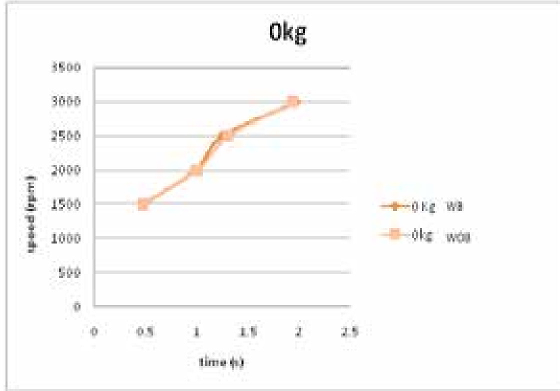
TABLE 6. 2 Load test without blower
FP=12.4 (from graph, by Willan's Line method)

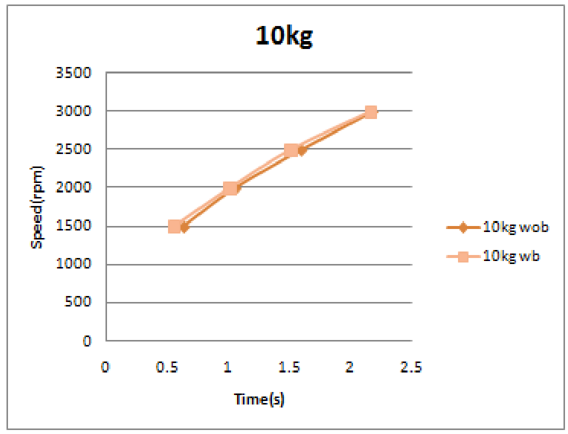
Load test with blower

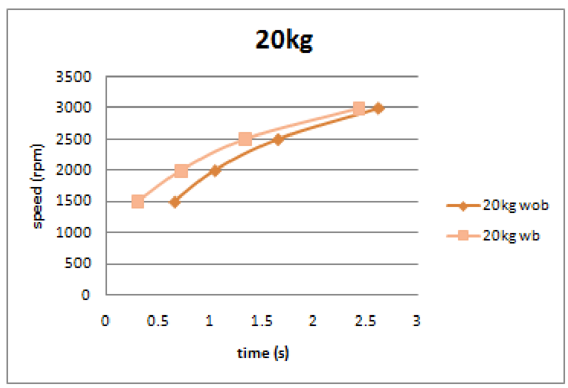
Load (kg)	BP (KW)	TFC (kg/h)	SFC (kg/KWh)	Break thermal efficiency, (%)	Indicated power,IP (KW)	Mechanical efficiency, (%)	Indicated thermal efficiency, (%)
0	0	1.874	∞	0	12.9	0	59
10	4.109	2.830	0.6887	12.45	17.009	24.16	51.52
20	8.128	2.93	0.3565	24.04	21.118	38.9	61.78
30	12.328	3.451	0.2799	30.62	25.228	48.9	62.66
40	16.437	3.6054	0.2193	39.07	29.337	56.02	69.75

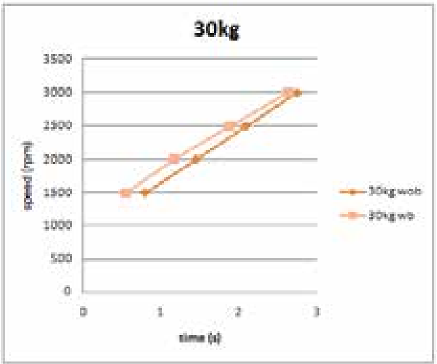
TABLE 6. 3 Load test with blower
FP=12.9(from graph, by Willan's Line method)

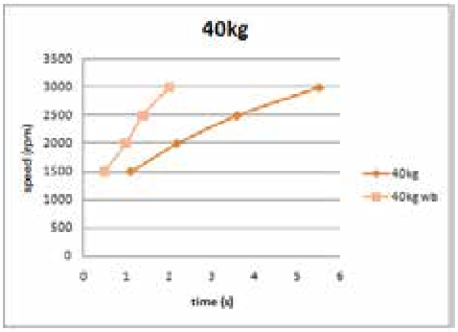
GRAPH FOR ACCELERATION TEST
Blower speed 2



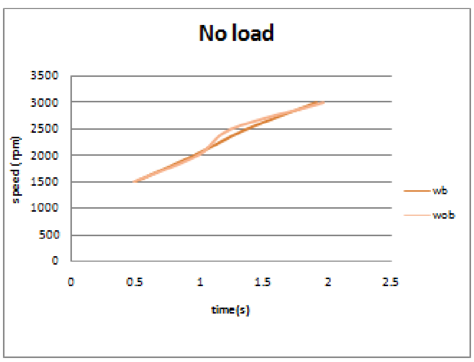


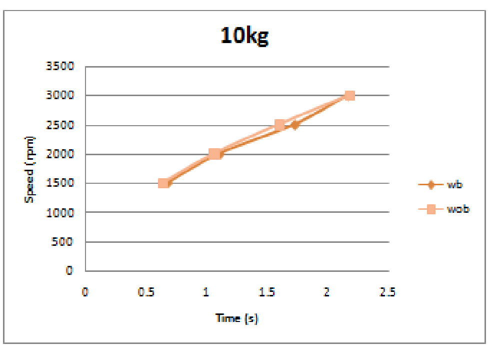


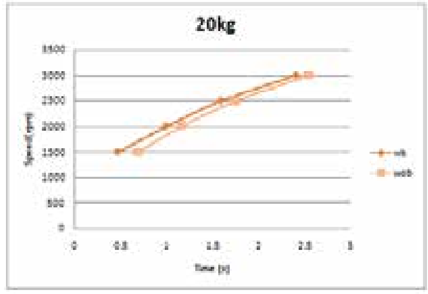


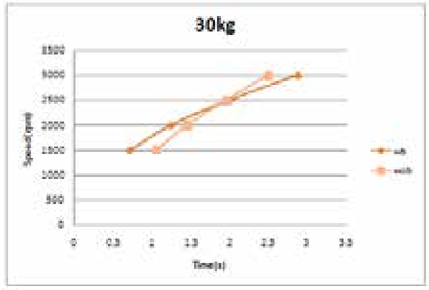


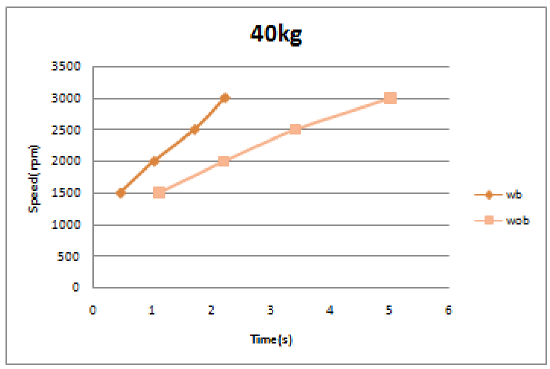
Blower speed 3



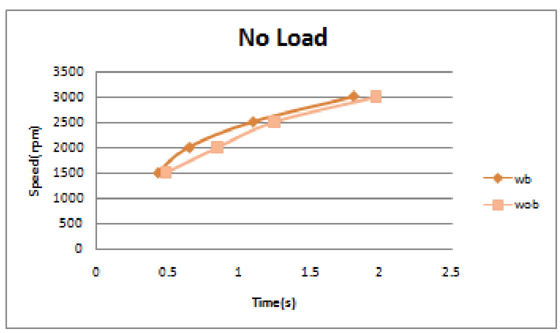


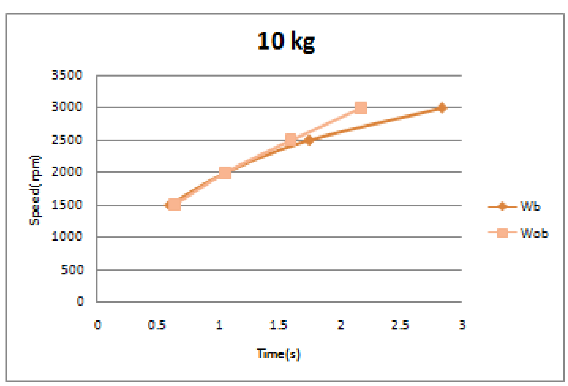






Blower speed 1





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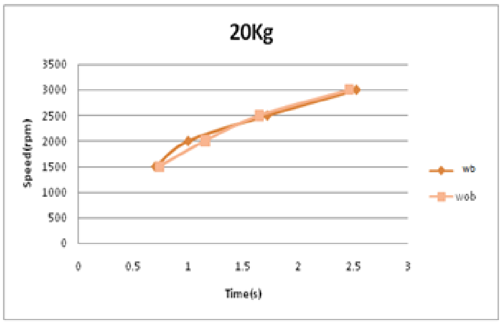
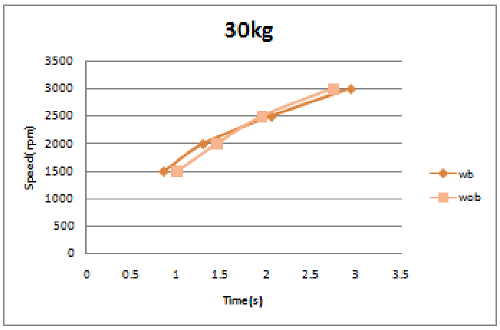
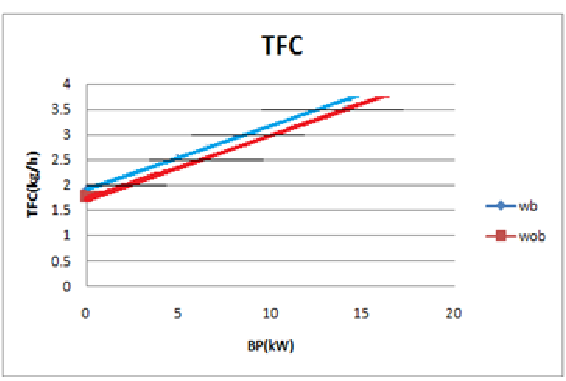


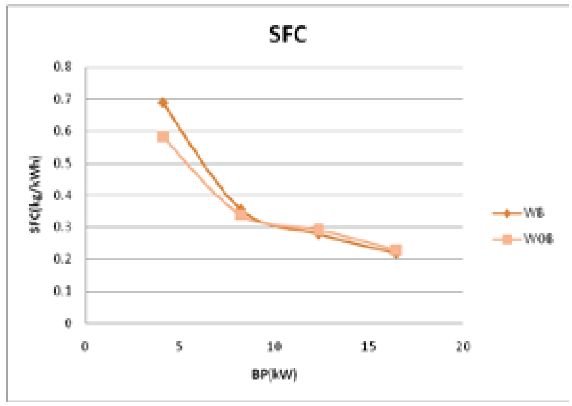


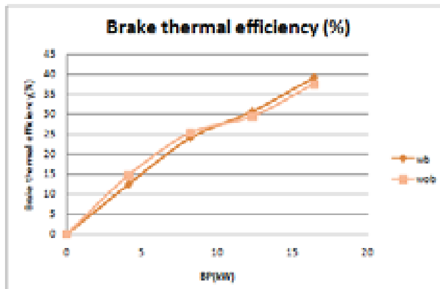
It is seen from the graphs that engine takes much time to reach rpm ranges (1500, 2000, 2500, 3000) without the blower unit than with blower connected to the engine. During lower engine speed the engine cannot suck enough air for effective combustion; here we are providing excess air to the combustion chamber with the help of blower. As more air is induced into the combustion chamber during the period of turbolag effective combustion will take place. As a result the engine can attain its maximum performance in less time. In short, the blower is providing more air as needed by the engine in order to make combustion more efficient. So the turbolag could be minimized to an extent. This will be more evident in the case of higher loads, (here 40kg).

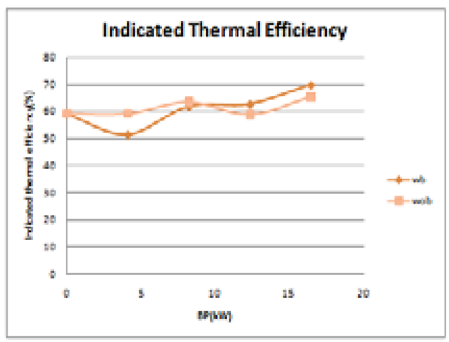
The above result is tabulated for blower **speed 2**. Since our blower is variable speed type we have tested the experiment in other speed also. The speed more than 2 leads to back flow of air and also it is less effective. For **blower speed** 1 the effect is positive but still less when compared to blower speed 2. These variations are shown in figure below.

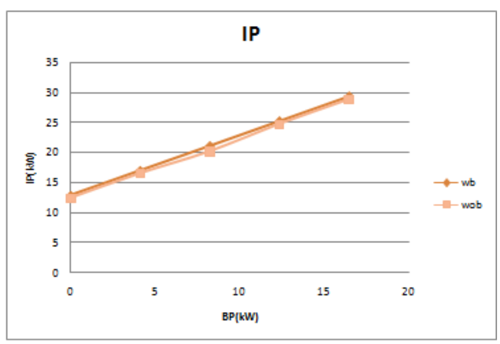
LOAD TEST

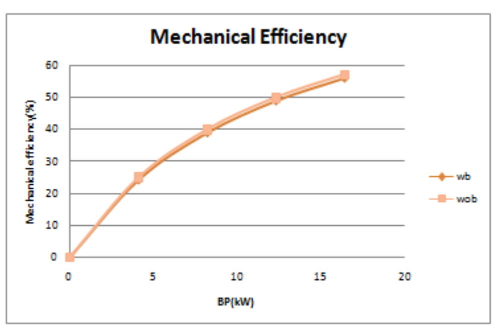












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INFERENCE FOR LOAD TEST

The graph of TFC vs BP is obtained as a straight line which shows the linear relationship between TFC and BP in both cases (with and without blower). While all other graphs SF vs BP, BTE vs BP, ITE vs BP and Mech. Efficiency vs BP are obtained as curves in both cases. This is because when the applied load increases, temperature in the engine increases .This rise in temperature causes the heat to get lost through the exhaust gas. For Higher temperature heat lost through exhaust gas is higher. So curves are obtained instead of straight lines. The pattern of fuel injection may also cause the variation in graphs.

Engine when connected to Blower

The variation of efficiencies with respect to Brake power, is to its maximum as follows

Brake Thermal efficiency -39.07% at BP = 16.437 KW

Indicated Thermal efficiency - 69.75% at BP = 16.437 KW

Mechanical efficiency - 56.02% at BP = 16.437 KW

Engine without Blower

The variation of efficiencies with respect to Brake power, is to its maximum as follows

Brake Thermal efficiency -37.43% at BP = 16.437 KW

Indicated Thermal efficiency - 65.407% at BP = 16.437 KW

Mechanical efficiency - 56.99% at BP = 16.437 KW

From the above results we can see 1.64% improvement for the brake thermal efficiency. This increment is due to the decrease in TFC value, which means that the fuel consumed by the engine when connected to the blower is more. So accordingly the power delivered by the engine will be more at lower rpm. The main problem faced by an engine due to turbolag was the unavailability of sufficient power at lower rpm. This problem gets rectified to a large extent by means of connecting the blower unit.

The Frictional Power for the engine working without the blower is found out to be 12.4 KW and with blower is found to be 12.9KW.The frictional power produced by an engine will be always constant .But here the variation maybe due to the supply of additional volume of air without any modification to the engine cylinder and other concerned parts.

7.CONCLUSION

One of the major challenges faced by the automobile industry is the turbo lag in diesel engines. A turbocharger is a turbine-driven forced induction device that increases an engine's efficiency and power by forcing extra air into the combustion chamber. This improvement over a naturally aspirated engine's output results because the turbine can force more air and proportionately more fuel into the combustion chamber than atmosphere pressure alone.

Several methods were followed by our team members in order to reduce the turbo lag in diesel engines.

First method which we try to implement was, to couple a motor to impeller shaft of the turbocharger by extending the turbo shaft. But practically this method found out to be complicated and apart from this in order to couple the motor we need to extend the shaft from the turbo so there aroused a problem of turbo balancing

So from further studies we found out that the impeller speed could be increased by using the compressed air from an air compressor. This addition of compressor to the engine made the assembly bulky, and there was a need of nozzle for effective rotation of impeller blades. But this can lead to the disturbance and obstruction to the passage of the inlet air from air filter. So we had to find another alternative.

Finally we substituted this compressor with a blower, which overcomes the problem of bulkiness. We tried to connect the blower without any nozzle as it can lead to obstruction, so we just directly connected the blower output at a distance which is not far from the impeller fan using a pipe But the design of the impeller blade reflected back 80% of the air from the blower and blocked the inlet air passage. Then we attempted by reducing the blower speed but sufficient air to rotate the impeller blade was not obtained. So we changed the position of the blower and placed it at the inlet of the turbocharger pipe. This increased the turbo speed by acting as boost to the already passing air from air filter. And we could notice the engines performance get altered by a wide margin.

From the results obtained it is evident that there is a considerable improvement for the brake thermal efficiency. This increment is due to the decrease in TFC value, which means that the fuel consumed by the engine when connected to the blower is more. So accordingly the power delivered by the engine will be more at lower rpm. The main problem faced by an engine due to turbolag was the unavailability of sufficient power at lower rpm. This problem gets rectified to a large extent by means of connecting the blower unit.

The Frictional Power for the engine working without the blower is found out to be 12.4 KW and with blower is found to be 12.9KW.The frictional power produced by an engine will be always constant .But here the variation maybe due to the supply of additional volume of air without any modification to the engine cylinder and other concerned parts.

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