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Effect of Variable Geometry Turbocharger (VGT) on Diesel Engine efficiency

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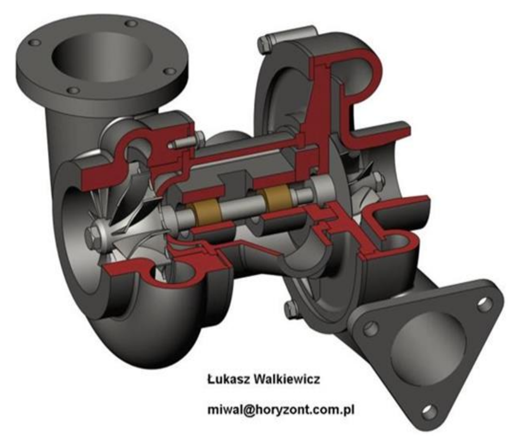
Abstract - The purpose behind this study of variable geometry turbocharger is to overcome the fundamental drawback of the internal combustion engine, its volumetric efficiency limit. Here, The VGT with no waste gate uses the exhaust energy to drive the turbine, which in turn drives the compressor to increase the volumetric efficiency and simultaneously increasing the expansion ratio, power output, Output Torque and to get the increased results on an IC Engine. This additional power, the alternate power must be much more convenient in availability and usage.

Keywords – Variable Geometry Turbocharger(VGT), Aspect Ratio(A/R Ratio), Efficiency, Lag, Wastegate.

INTRODUCTION

Diesel engine manufacturers need a way to improve fuel economy to increase the performance and efficiency of engine. A large percentage of fuel consumption occurs during cold start and light to medium load operation. It is recommended to develop a method to increase combustion chamber temperature during warm-up, light and medium loads that will improve fuel efficiency. One of the major factor which affects the engine efficiency is the air-fuel ratio in the combustion chamber.to meet these requirements a turbocharger can be employed. A turbocharger is a turbine that is driven by exhaust gases that compresses incoming air into the engine. The "hot" side of the turbo receives its energy from the heat and flow energy of the exhaust system.

The "cold" side of the turbocharger pressurizes fresh air and forces it into the engine. The pressure generated by the "cold" side is called the boost. The "cold" side is driven by a shaft that is connected to the "hot" side. So basically the turbocharger uses the pressure energy of the exhaust gases and converts it into kinetic energy to drive the turbine of the turbocharger .



There are various type of turbochargers which are used like Single turbocharger, sequential turbocharger, twin scroll turbocharger, variable twin scroll turbocharger, electrical turbocharger, variable geometry turbocharger(VGT) , etc. The figure shown is the cross section of turbocharger.

DRAWBACKS OF SIMPLE TURBOCHARGER

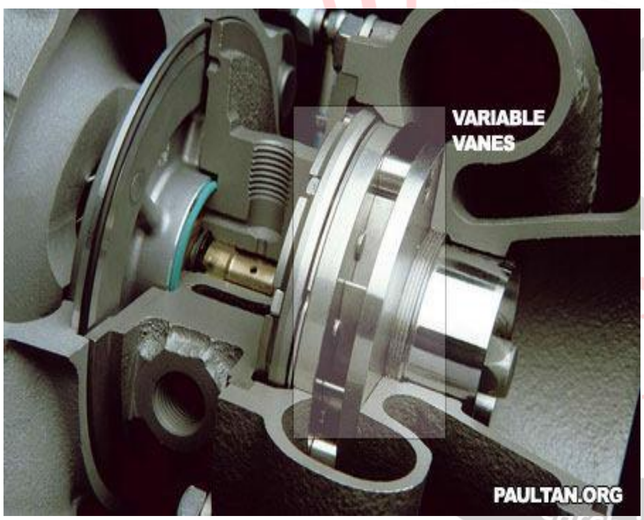
The main drawback to a turbocharger, besides cost, is its fixed geometry. The Aspect Ratio (A/R) of a turbo, which is based on its geometry, has a direct relation to both the power increase generated and the motor speed at which the power increase is generated. A smaller A/R will produce boost pressure at a lower engine speed, but will be unable to provide a high enough flow rate at higher engine speeds. . This leads to higher exhaust manifold pressures, lower pumping efficiencies, and lower power output. A larger A/R will create boost at higher engine speeds, and thus create more power, but it will be unable to produce boost at lower engine speeds. So an A/R must be picked to either, produce power at lower engine speeds for quicker acceleration, or for higher engine speeds to produce a greater total power.

TURBO LAG: The time turbocharger takes for the engine to produce boost between transients is called lag. A large A/R turbo will have a longer lag time than a smaller A/R turbo due its larger requirement of energy from the engine to produce boost.

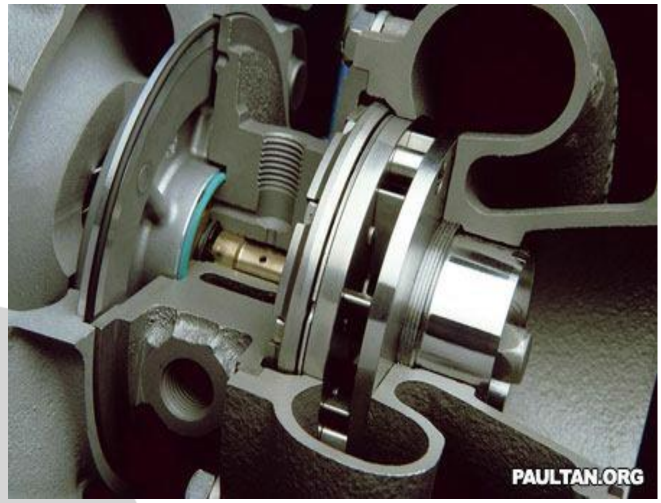
Variable Geometry Turbocharger(VGT)

Variable Geometry Turbochargers are turbochargers whose geometry and thus effective A/R can be altered as needed while in use. The most common design includes several adjustable vanes around a central turbine. As the angle of the vanes change, the angle of air flow onto the turbine blades changes, which changes the effective area of the turbine, and thus the aspect ratio (A/R) changes.

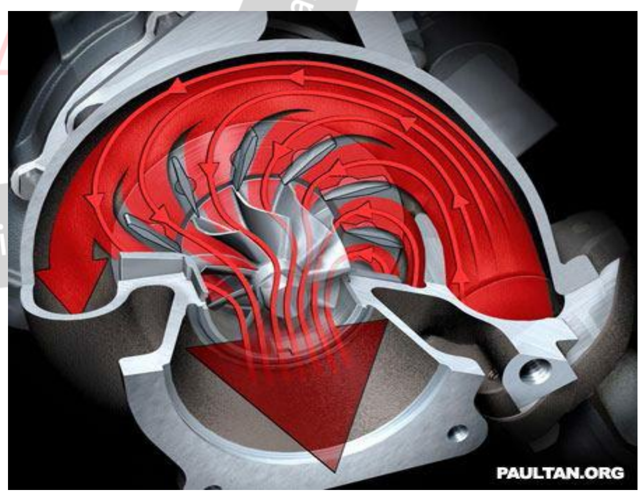
NEED OF VARIABLE GEOMETRY TURBOCHARGER



In boosting the power of the engines, the application of Conventional turbochargers could realize only a limited improvement because it is effective in a narrow flow range of operation. Charging effect of turbocharger is too poor in a low flow range below the matching point to realize a high power output at a low engine speed region. For boosting high speed Diesel engines, the waste gated turbochargers that bypass some fraction of an exhaust gas are normally used. But, recently, VGT is increasingly used in High speed direct ignition (HSDI) Diesel engines, which raise the boost pressure even at lower rpm of engine, along with the reduction of pumping losses at higher engine speeds compared to a waste gated turbocharger. In this trial, a Variable Geometry Turbocharger was applied to an High speed Diesel engine, and the enhancement of a full load performance over the case with a mechanically controlled waste gated turbocharger is obtained.



In the 3D illustration above, you can see the vanes in a angle which is almost closed. I have highlighted the variable vanes so you know which is which. This position is optimized for low engine RPM speeds, pre-boost. In this cut through diagram, you can see the direction of exhaust flow when the variable vanes are in an almost closed angle. The narrow passage of which the exhaust gas has to flow through accelerates the exhaust gas towards the turbine blades, making them spin faster. The angle of the vanes also directs the gas to hit the blades at the proper angle.



Above are how the VGT vanes look like when they are open. I've not highlighted where the vanes are in this image since you already know where they are, as to not spoil the mechanical beauty. This cut-through diagram shows the exhaust gas flow when the variable turbine vanes are fully open. The high exhaust flow at high engine speeds are fully directed onto the turbine blades by the variable vanes.

WORKING: Variable geometry turbocharger use vanes to alter the air flow path of the exhaust gases to maximize boost across the entire revolution range. During low boost operations, the vanes create a narrow path to the exhaust turbine. As the revs increase and exhaust builds, an actuator rotates the vanes, increasing the area of the path to the turbine, and allowing for greater flow, thus increasing boost at higher RPM.

Increasing Efficiency

Turbochargers in general are a very good way to improve the efficiency of an engine. By pressurizing the intake manifold, more air, and thus more fuel, is brought into the cylinder every time the intake valve opens. This creates a volumetric efficiency of greater than 1. A volumetric efficiency of even 1 is impossible in any real engine without some kind of forced induction due to friction losses. This improves the overall efficiency of the engine by allowing it to burn more air and fuel on every cycle. The high positive pressure generated also helps to overcome any casting defects in the manifold, such as surface roughness (major losses) or tight corners (minor losses), by providing a larger driving force, or pump head. Fixed geometry turbochargers (FGT) work as any other centrifugal pump and thus have a limited optimal operating range. VGTs have the advantage that many different pressure ratios can be produced at a single engine speed due to the variable vanes changing the effective area and A/R. The vanes can be manipulated to create an optimal boost pressure at any speed. By producing an optimal boost through a larger engine speed range the overall efficiency is increased.

ADVANTAGES

No throttling loss of the waste gate valve.

Higher air–fuel ratio and higher peak torque at low engine speeds.

Improved vehicle accelerations without the need to resort to turbines with high pumping loss at high engine speeds.

Potential for lower engine ΔP (the difference between exhaust manifold and intake manifold pressures).

Control over engine ΔP that can be used to drive EGR flow in diesel engines with High Pressure Loop (HPL) EGR systems.

A better ability to cover a wider region of low BSFC in the engine speed–load domain.

CASE STUDY

Variable geometry turbines (VGT) have particular interest to advanced diesel powertrains for future conventional trucks, since they can dramatically improve system transient response to sudden changes in speed and load, characteristic of automotive applications. The VGT technology considered as a method to eliminate turbo lag, as well as to improve low speed boost and torque because the conventional turbochargers charging effect is too poor in a low flow range below the matching point requiring a high power output at a low engine speed region. But in the VGT boost pressure can be created at the lower speed and reduction in the pumping losses at the higher speed of engine . In this study applying the VGT turbo and conventional waste gated turbo to the high speed direct injection (HSDI) diesel engine and comparing the performance characteristics of the both cases. The vehicles used are international class VI 4700 series delivery truck having the vehicle and driveline specifications as follows:

GVWR	7950 (Kg)
Wheelbase	3.7 (m)
CG location	2.2(in m from front
Frontal area	5 (m 2)
Air drag coefficient	0.8
Transmission	4 speed automatic

The engine simulation used is the V8 DI 7.3l diesel engine The specifications of the engine are as follows :

Configuration	V8
Displacement	444 cu in.
Cylinder bore	104.4mm (4.11 in)
Piston stroke	106.2 mm(4.18 in.)
Power output	210-275hp(157-205kW)
Torque output	425-524lb.ft(576-712N.m)
Gove. Engine speed	2600 rpm

In the variable geometry turbocharger (VGT) flow area and the angle between the turbine volute and rotor can be changed which is not possible in the waste gated

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turbocharger. Therefore it increases the boost pressure at the lower speed enabling the high torque and it also reduce the fuel consumption at higher engine speed due to the high gap between the turbine volute and rotor.

As at the lower engine speeds vane angle is narrower exhaust gas get accelerated thus the boost pressure increased. This allows the More fuel delivery and higher torque is acquired. But due to the minimum, flow path turbine inlet pressure known as the engine back pressure increases. So it can be so high that fuel consumption may not be feasible. Therefore the improvement in the fuel consumption is necessary for the test. At the high pressure larger area of the flow passage is there and it can cause reduce in engine back pressure causing lower fuel consumption.

A. Experimental procedure For the comparison study of the VGT and conventional waste gate turbocharger engine system is run at the full load covering the entire RPM range of the engine at the same boundary condition of the fuel consumption. For the study two cases are considered. In case an engine is enhanced by the VGT and in the case B it is attached with the waste gate turbocharger.

In the both the cases the engine is accelerated between the 0-60 mph and the various engine parameters are calculated. The parameter such as the fuel injection time is kept same for the both cases. in the case of the VGT initial vane angle can cause the change in the starting boost pressure therefore the starting boost pressure is kept as same for the waste gate turbocharger. At initially the engine is start at the full load with breaks applied and after the 5 seconds breaks are released to achieve the maximum demand upto the 60 mph speed of the vehicle and the engine and vehicle parameters are measured. The parameters measured during each case are engine speed (rpm), vehicle speed (rpm), boost (bar), fuel injected (g/cycle), torque converter turbine torque (transmission in peak torque in N.m), wheel slip and F/A (fuel/air) equivalence ratio.

B. Test result From the given calculation the most important characteristics found out is the quicker response of the engine with the VGT. The slope of curve of engine speed at launch is very steep, as the result of the fact that the VGT turbocharger is able to build pressure in the intake manifold much faster; hence the injection system controller allows more fuel to be injected in the cylinder (see Fig.12).

The F/A equivalence ratio histories show spikes associated with the end of pressure build-up during the turbocharger transient (see Fig. 13). These excursions into a mixture richer that what is normally experienced under steady-state operating conditions obviously occur at different times, i.e. much earlier in the case of the engine with VGT. The unfavorable effect on emission of soot (unburnt carbon segregated) would be similar. However, with the improvement in the response so drastically, the fuel injection calibration could be changed to reduce fuelling during the critical part of the transient without sacrificing too much of the engine response. The sudden burst of engine torque combined with the increased slip ratio in the torque converter produces a much higher initial TC-turbine torque, i.e. transmission in peak torque. Hence, the time between launch and first gearshift is reduced by almost 2 seconds, and the overall 0-60 acceleration is improved considerably. The tire slip two seconds into the launch is also much higher and during that period tire wear would be increased[12].

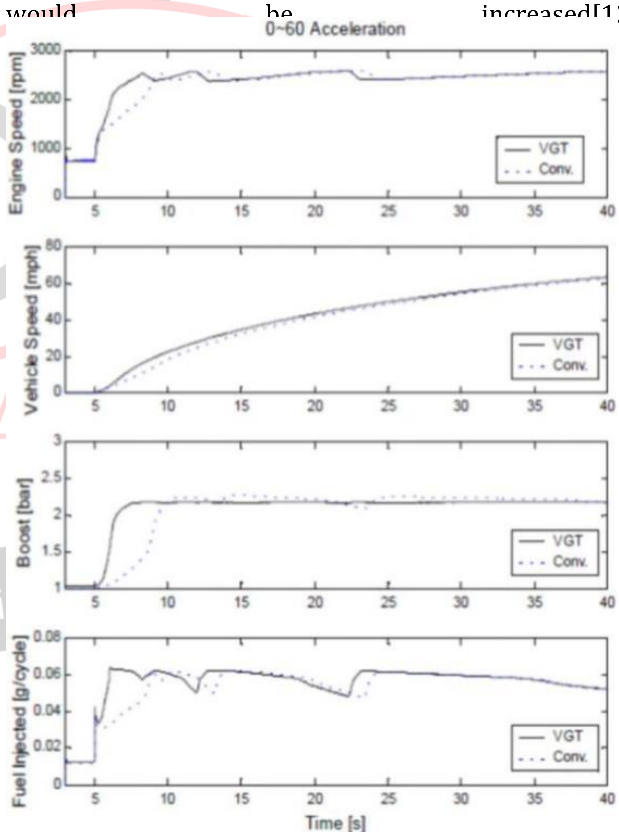

Fig. 12. Comparison between Engine speed, vehicle speed, boost pressure and fuel injected in combustion chamber of VGT and Waste gated turbocharger.

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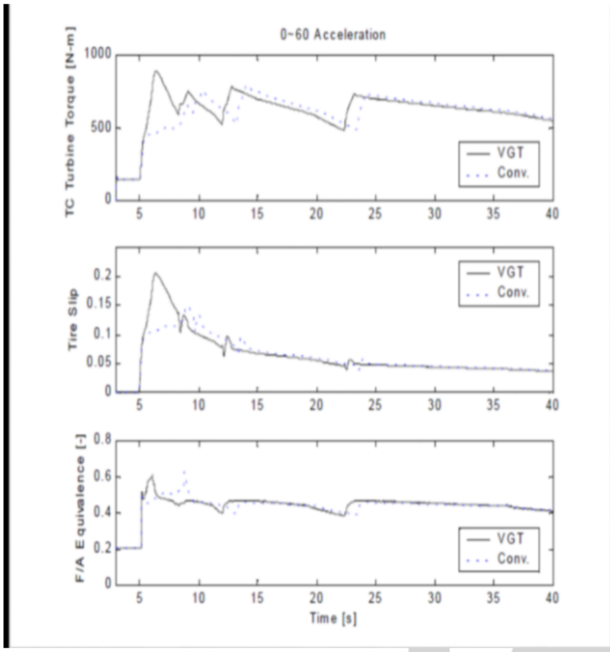

Fig. 13. Comparison between TC turbine torque, wheel slip and F/A equivalence ratio of VGT and waste gated turbocharger.

From the above data calculation observation says that due to use of the VGT charged air mass is increased by the 10-20% at low speed. Therefore exhaust smoke is reduced and the full fuel consumption will be occurred. At low speed we can see that 40% of increase in the torque. At the medium engine speed there is little gain in fuel consumption for VGT. Within the boundary condition we can say VGT can increase engine power by 8%. There will more tireslip at the low speed due to high torque generated.

CONCLUSION: The use of variable geometry turbochargers (VGT) considerably improve the efficiency of the Diesel Engines (HDSI) .They provide a great performance of engine , especially at low load condition. The boost pressure is kept high by adjusting the flow area of diffuser vanes .This results in high mean effective pressure which is beneficial at low engine speed .Also because of its design ,the same boost pressures can be achieved with much low engine back pressure ,by control of flow angle and area .This signifies that the engine can work more efficiently over a wide range of speed . At high engine speeds , engine power could be enhanced due to lower pump losses and reduced residual gas which gives better combustion environment . The emission levels can also be controlled by using VGT .

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