Selection of Wastegate setting for He200 Turbocharger

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Abstract: Turbocharger has a vital role in improving engine performance. This paper discusses about Waste Gate turbocharger working & its significance. This paper is based on the process followed to identify the optimal Wastegate setting in order to meet customer's requirements. There were total 6 Wastegate settings were tested from which one optimal wastegate setting need to be selected with the help of experimental results being evaluated. All the wastegate settings were tested with same cycles & compared the performance parameters like BSFC, BSNOx. WG setting is not the only criteria for performance of turbocharger, Turbochargers with different construction but having same wastegate setting can give different results. This paper only gives the information about fixing the WG setting for customers requirements. Further optimization can be done with different turbochargers. Most reliable option with good performance is selected for engine optimization.

IndexTerms - Turbocharger; Wastegate; Diesel engine; Emissions

I. INTRODUCTION

A Turbocharger is a turbine -driven forced induction device that increases an internal combustion engine's efficiency and power output by forcing extra air into the combustion chamber. This improvement over a naturally aspirated engines power output is due to the fact that the compressor can force more air—and proportionately more fuel—into the combustion chamber than atmospheric pressure (and for that matter, ram air intakes) alone. This paper includes selection of optimal wastegate setting of turbocharger in order to meet customers' requirements. There were total 6 WG turbocharger options listed for experimental trial from which one need to be selected with the help of experimental results.

A wastegate is a valve which redirects exhaust gases coming from the engine around the turbocharger so the gases are not used to spool the turbo. This is done to limit the amount of boost an engine creates as to not cause any damage and keep power levels at the desired level. The system works based on pressure. The actuator of the internal wastegate is connected to a pressure only source which means that whatever the pressure is within the pressure side of the turbocharger compressor, the sealed chamber is also at the same pressure. As the pressure of the air being compressed by the turbocharger increases, the pressure within the sealed chamber of the actuator increases which applies a force on the spring. When the pressure is high enough to overcome the spring force, the wastegate valve begins to open, diverting exhaust gas around the turbine, allowing it to maintain its speed. If the pressure drops, then the spring pushes the valve shut and allows the turbine to build up speed. If the pressure increases, then the valve will open further, bypassing more exhaust gas to try to maintain the desired pressure. The exhaust gases will choose the path of least resistance, so gas will travel through the wastegate so long as peak boost is held. Without sufficient exhaust gases, the turbo will not be able to increase boost pressure.

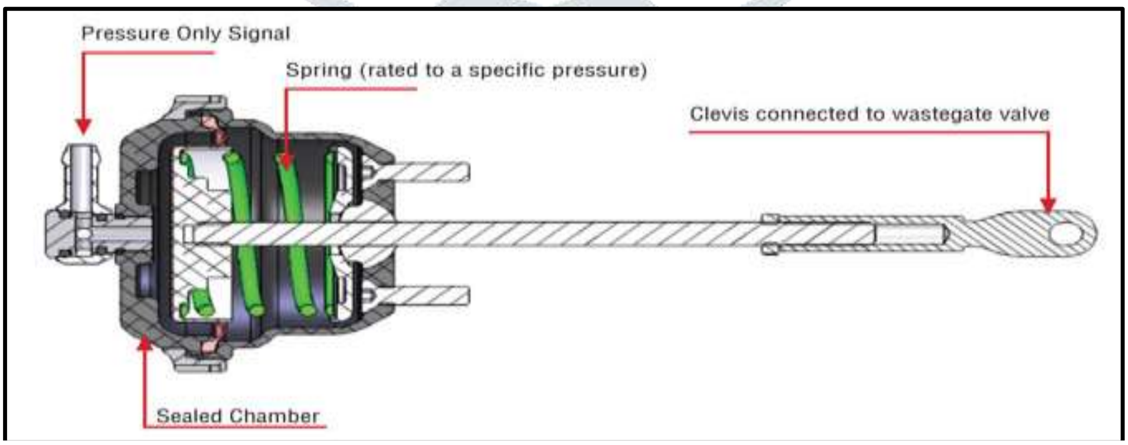

Figure 1 Spring loaded wastegate valve

Another important definition is the phi parameter. The phi parameter is nothing more than a numerical representation of the stage (wheel + housing) swallowing capacity. The number is calculated by knowing the mass flow, temperature, and pressure of the incoming gas.

$$Turbine\ flow\ parameter(Phi) = \frac{mass\ flow * \sqrt{absolute\ temperature}}{absolute\ pressure}$$

Knowing the phi parameter for the stage and comparing that number to the engine exhaust manifold outlet conditions will describe whether or not the turbine can swallow what the engine is emitting. Any flow above and beyond the phi capacity must be wastegated. If the flow is less than the phi capacity, then the turbine is oversized and the boost target will not be achieved at that engine speed and load. This numerical comparison (point by point) is what is referred to as turbine matching and is substantially more involved than compressor matching [1].

Waste gate actuator acts to open the waste gate at a set boost pressure and vent out part of the exhaust gases before hitting the turbine wheel. The simplest closed-loop control for a wastegate is to supply boost pressure directly from compressor side to the wastegate actuator. A small hose can connect from the turbocharger compressor outlet to the nipple on the wastegate pneumatic actuator. The wastegate will open further as the boost pressure pushes against the force of the spring in the wastegate actuator until equilibrium is obtained.

Looking into details of forces acting on the waste gate, its spring pre-load, Compressor out Pressure (boost signal connected to pneumatic actuator), Turbine in pressure and Turbine out pressure. The spring pre-load and the turbine out pressure acts on the waste gate to keep it closed whereas the Turbine in pressure and Compressor out pressure acts on the other side trying to open the waste gate.

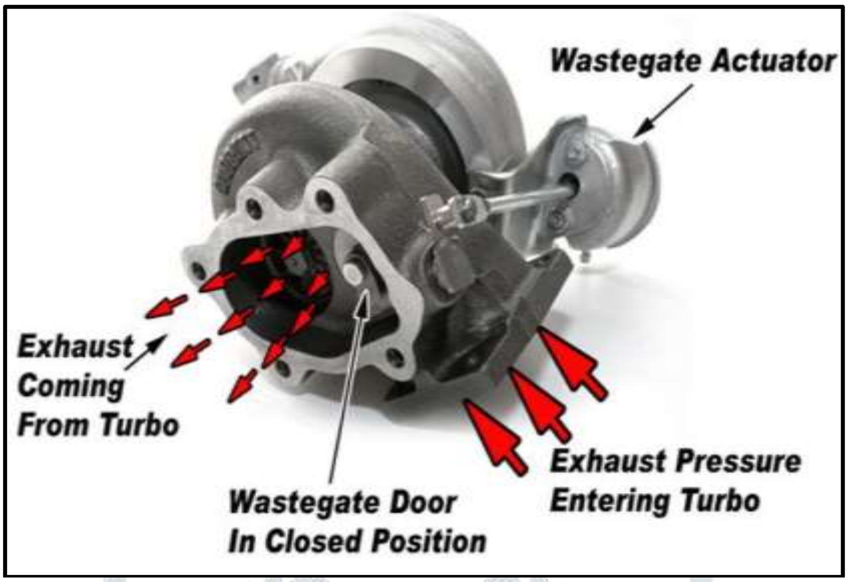

Figure 2 Wastegate Turbocharger

II. Literature Survey

Mohd Muqeem, Dr.Mukhtar Ahmad, Dr.A.F, Sherwani [2] from his literature review studied the Impact of Turbocharger Non-Adiabatic Operation on Engine Volumetric Efficiency and Turbo Lag .It also gives up the information about the Effect of Variable Geometry Turbocharger. The full load performance result with VGT & waste-gated turbocharger are compared. Within the same limitation of a maximum cylinder pressure and exhaust smoke level, the low speed torque could be enhanced by about 44% at maximum. Mohd Muqeem, Dr.Manoj Kumar [4] suggeated that in coming days there will be increase in the demand of fuel efficient engines with more power and minimum emissions and this is possible with some advancements in turbocharging technology. From this literature review it has been concluded that from last two decades various attempts were made to improve the power output of an engine and to reduce its emissions by making some changes and installing some additional accessories like intercooler in the turbocharging technology. Z.S. Lad*, Nikhil S. Mane, H.M.Dange [5] showed positive influence of turbocharger on IC engine power characteristics as well as emission characteristics. But in turbocharging air fuel ratio is always constant, so we can optimize air/fuel ratio & can be used at appropriate speed load.

Naser et al. [6] focused on turbocharged diesel internal combustion engine. He concluded, as compressor outlet air pressure increase we get hot intake charge so because of reduction in density performance reduces. Passing charge through an intercooler reduces temp so density will increase, more air will go in & performance of turbocharger increases. Eyub et al [7] used Intercooler to cool the charge, so that density will increase, more amount of energy can be used & because of this performance will improve. Due to the denser air there is possibility to reduce knock & downsizing is also possible. Engine power output can be increased 154% by ideal intercooler while single turbocharger without intercooler can only increase 65%. Muqeem [8] suggested by using intercooler, intake air temperature can be reduced, so there will be more density & more air can be used & performance will be more. Here, the purpose of author was to bring the temperature of intake air nearer to the ambient temperature. Here the author concluded that when normal air-cooled intercooler is used to cool down the hot air before entering into the engine cylinder, the mass of oxygen being fed to the engine becomes 1.43 times but when refrigerated intercooler is used, it becomes 2.618 times. Increasing the oxygen content with the air leads to faster burn rates and the ability to control exhaust emissions.

III.Performance Parameters & Calculations

3.1 Boundary conditions:

Table 1 Boundary conditions for Testing:

Parameter	Unit	Value	Tolerance
Intake Restriction	kPa (Rated)	-3.75	+/-1
Coolant outlet Temperature	Deg C	93	+/-3
Fuel Inlet Temperature	Deg C	40	+/-2
Fuel Inlet Pressure	kPa	0-20 kPa	+/-1
Fuel Return Pressure	kPa	0-20 kPa	+/-1
Combustion air Temperature	Deg C	25	+/-2

NTP Pressure	kPa	100	+/-0.2
Humidity	%	40	+/-3

Meeting the Boundary conditions is the most important requirements for any test; any data can be compared only if boundary conditions set properly.

3.2 Mechanical Limits: Mechanical limit is the most important criteria, while testing any engine there should be mechanical limits so that there should not be any incidence that is violating safety or there should not be mechanical damage to the engine. So, in every engine some safety limits are fixed. These limits are fixed by studying the fatigue life & other material properties of the engine. If engine starts operating above these limits alarm can be observed or at extreme conditions engine may abort to avoid any further damage. Below given are the mechanical limits which generally fixed.

1. Turbine Inlet Temperature: 680 Deg C
2. Peak cylinder pressure: 150 Bar
3. Blowby: 80 L/min
4. Smoke: 2FSN

3.3 Calculations for BSFC & BSNOx:

1. BSFC: Basic specific fuel consumption

BSFC (G/KW-HR) = Fuel rate/Power

= Fuel rate (Kg/hr)/Power (K-w) *1000

2. BSNOx is measured parameter; it is measured with the help of emission bench. But the values which get from emission cart are in PPM, so it is converted to gram/kW-hr by using conversion formulae.

IV.Turbocharger Specification Mapping

Wastegate turbocharger was used for testing. So, first aim should be to finalize the Waste gate setting. Different wastegate settings were tested and engine was run to verify required performance. According to requirement, Wastegate setting was loosened by 4,6,7.5,8, & 10 turns. Six different WG setting were ran to check the performance. First important performance parameter was to meet torque curve. After meeting torque WG setting was fixed on the basis of BSFC & BSNOx by staying in the mechanical limits.

Effect of wastegate setting pressure on Performance:

Wastegate setting pressure will reduce after loosening the spring. As spring is loosened, setting pressure reduces, because of this less pressure will be required to open the Wastegate i.e. compressor will generate lesser pressure this leads to lower airflow. It will reflect in other parameters. As airflow reduces combustion of fuel will be poor, which gives poor BSFC & lower BSNOx. Also, mechanical limits may affect. So, WG setting should be fixed such that, it will give good BSFC by staying in the limits of mechanical limits & BSNOx.

4.1 Target Performance Torque Curve:

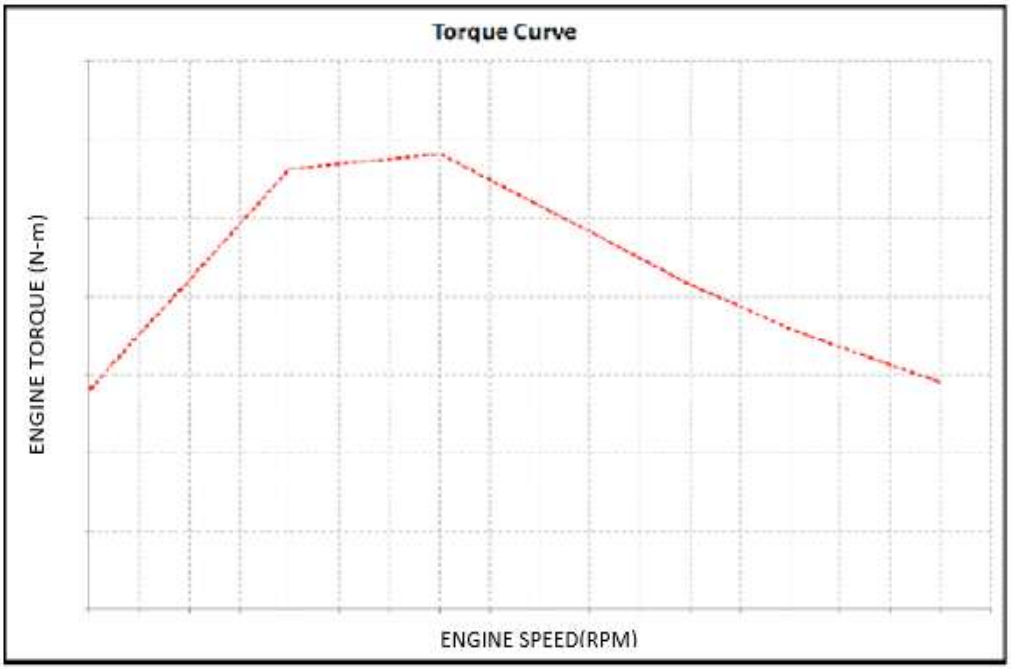

Figure 3 Engine torque vs engine speed (Target Performance)

According to the customer's requirement Target curve of Torque vs Speed was given which was the first target. This target torque curve was given by the customer on the basis of application which they are going to apply. For this purpose, performance was checked with different WG settings. After achieving this target curve, it was tuned to achieve other performance parameters.

4.2 Performance – with base (FG), 4, 6, 7.5, 8 & 10 turns WG specification

4.2.1. Torque curve

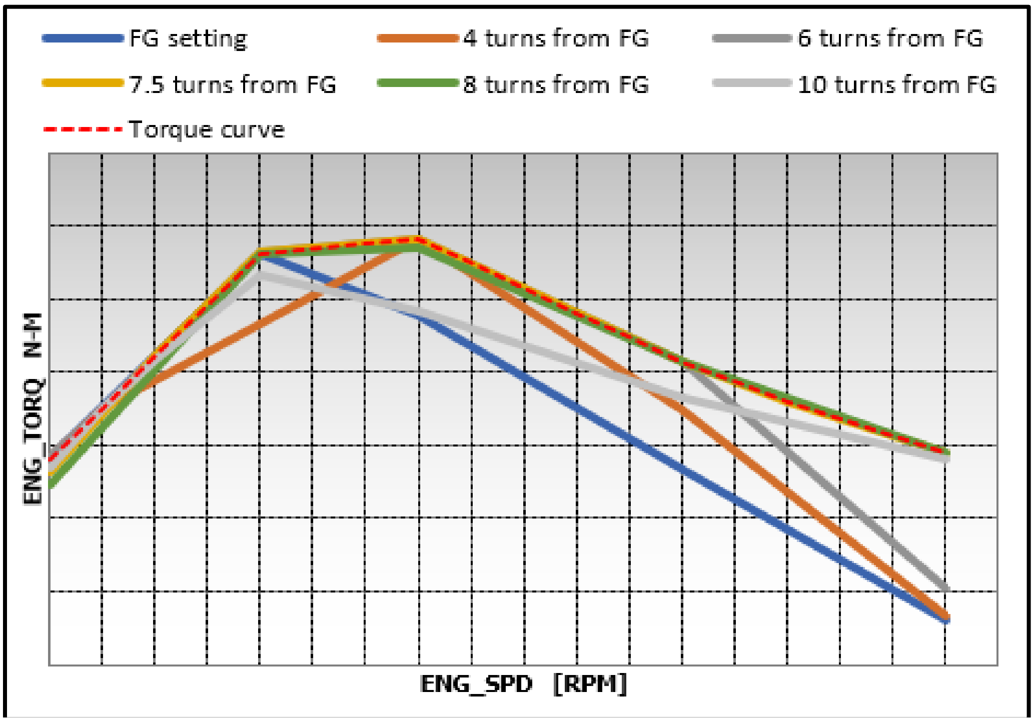

Figure 4 Engine torque vs engine speed (Comparison of Target performance with base (FG) 4, 6, 7.5,8 & 10 turns loosened WG setting)

Above plot showing the performance of base Fixed Geometry(FG) WG setting, 4, 6, 7.5, 8 & 10 turns loosened WG setting Turbocharger. From the plot it can be concluded that torque curve has not reached target curve with base (FG), 4, 6, 8 & 10 turns WG setting. With 6 turns it has reached required torque partially but it does not satisfied the torque at higher speeds. But for 7.5 & 8 turns WG setting target Torque curve is achieved completely. So other settings can't be used for performance testing.

Torque curve with 7.5 & 8 turns WG setting:

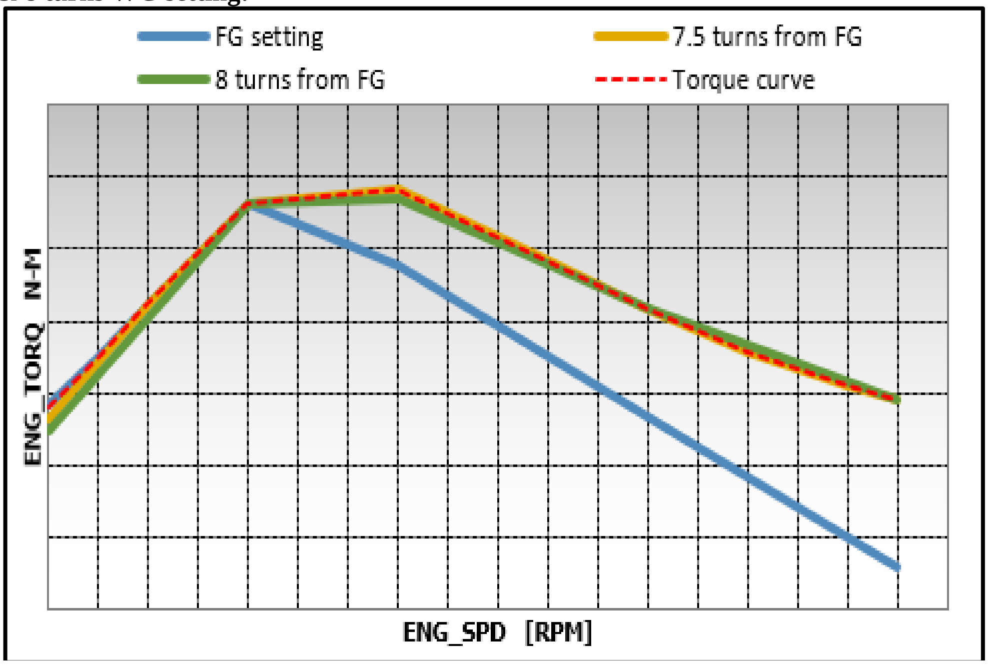

Figure 5 Engine torque vs engine speed (Comparison of Target performance with best turn)

Above plot showing performance with 7.5 & 8 turns loosened WG setting Turbocharger. From the plot it can be concluded that required torque curve is matched so this WG setting can be used for further performance testing. WG setting was fixed by comparing performances with these two WG setting.

4.2.2. Compressor outlet pressure & airflow:

Compressor outlet pressure defines airflow i.e. if compressor outlet pressure is low, airflow will be lower. As WG setting was loosen, the airflow reduced, due to this turbine inlet temperature increased. So, it was important to fix the setting such that required output can be achieved by staying within the mechanical limits. Below given is the compressor outlet temperature & airflow comparison with different WG setting.

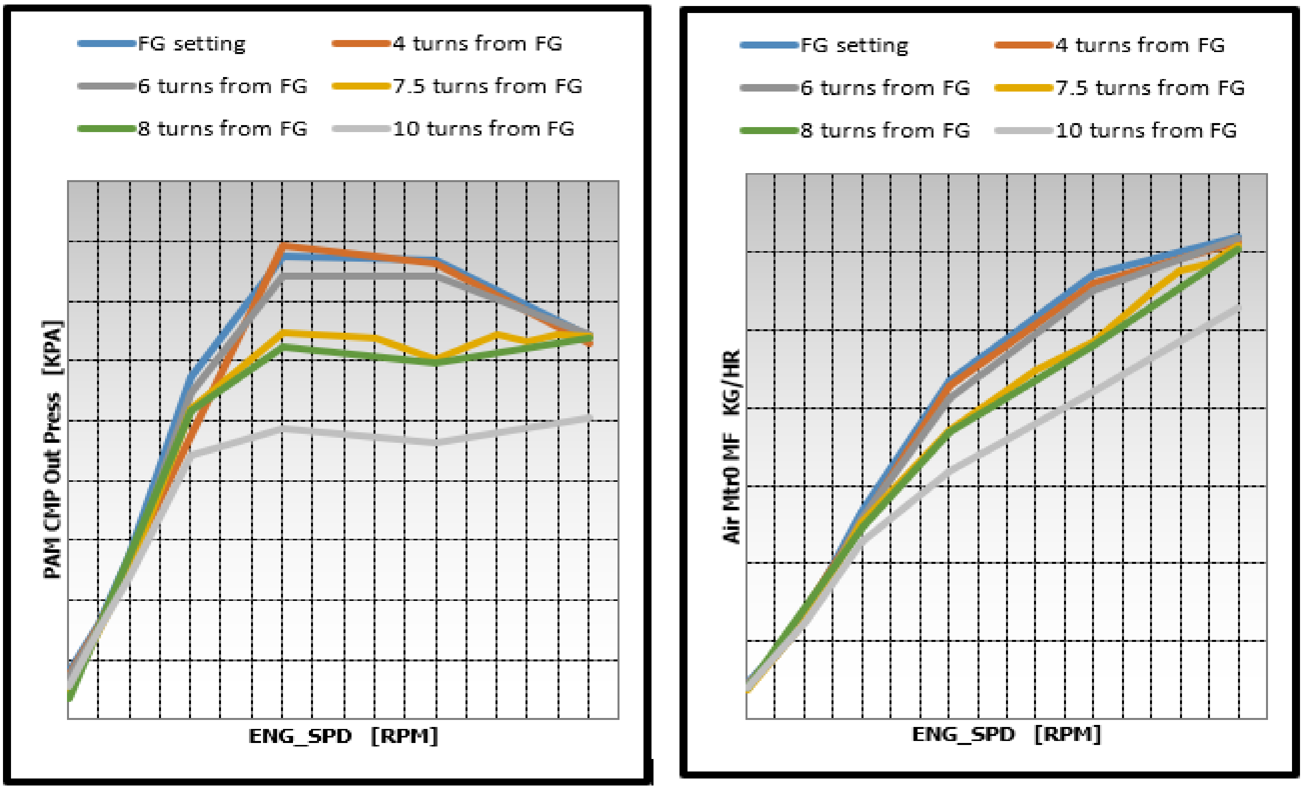

Figure 6 Compressor outlet pressure & airflow Comparison for base (FG) 4, 6, 7.5,8 & 10 turns loosened WG setting

From the above plots it can be concluded that as WG setting is loosened compressor outlet pressure & airflow is reduced. After this WG setting should be fixed on the basis of mechanical limits & BSNOx-BSFC trade off.

4.2.3. Turbine inlet temperature:

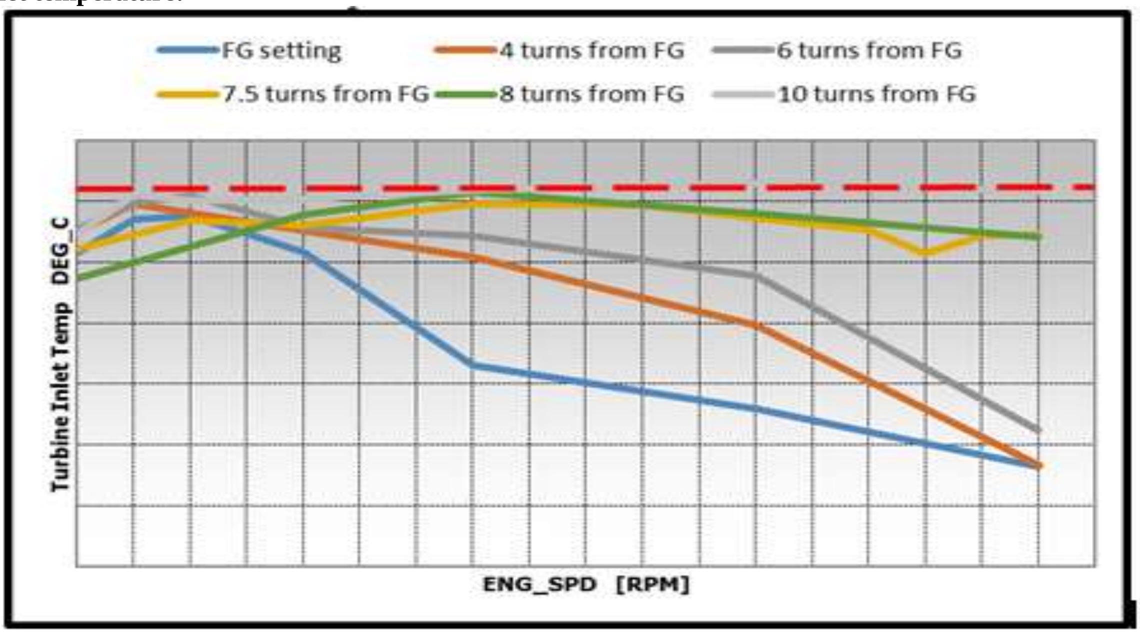

Figure 7 Turbine inlet temperature comparison for base (FG) 4, 6, 7.5,8 &10turns loosened WG setting

Above graph is showing comparison of turbine inlet temperature for different WG settings. Red line is showing the limit for turbine inlet temperature, it can be concluded that with 10 turns WG setting TIT limit is violated. TIT was higher because of lower airflow, so WG setting was selected having higher airflow than 10 turns setting.

4.2.4. BSFC & BSNOx:

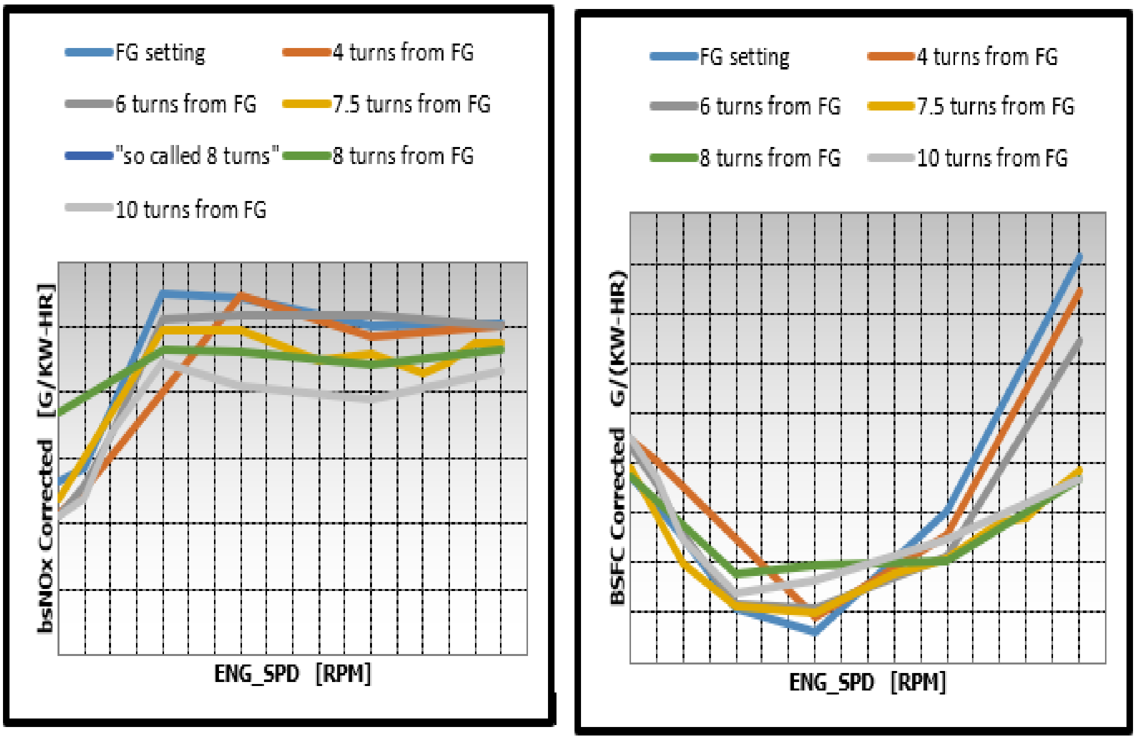

Figure 8 BSFC & BSNOx comparison for base (FG) 4, 6, 7.5,8 &10turns WG setting

Above plot is showing BSFC & BSNOx comparison for base (FG) 4, 6, 7.5,8 &10turns loosened WG setting. Torque was achieved with only 7.5 & 8 turns WG setting. From the plot, it can be concluded that BSFC & BSNOx are showing better trends for 7.5 turns WG setting. So, 7.5 turns WG setting was finalized

Waste gate setting was fixed, it was very important to convert it to Engineering measurable specification. For this purpose, WG pressure detection test was conducted on the turbocharger. From the WG pressure detection test it was concluded that the setting pressure as 1.9 Bar.

So further testing was done on turbocharger having waste gate setting pressure as 1.9 bar.

V. CONCLUSIONS

From the experimental results it can be concluded that WG setting of turbocharger plays very important role in performance of turbocharger. As WG setting spring is loosened, spring force reduces. So, pressure required to open the wastegate reduces. This pressure is sensed from the compressor outlet, so compressor outlet pressure will be lower that implies compressor can generate lower airflow. After comparing the performance Wastegate setting with 7.5 turn loose setting is selected. It was very important to convert it to Engineering measurable specification. For this purpose, WG pressure detection test was conducted on the turbocharger. From the WG pressure detection test it was concluded that the setting pressure as 1.9 Bar. WG setting is not the only criteria for performance of turbocharger, Turbochargers with different construction but having same wastegate setting can give different results. Further optimization can be done with different turbochargers having same wastegate setting, say 1.9 Bar.

VI. Acknowledgment

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