TWO STAGE TURBO-CHARGER, ITS MATCHING & SUBSEQUENT EMISSION CONTROL OF DIESEL ENGINE: A REVIEW

Aniruddh H. Bulbule*, Dr. Abhay A Pawar**

Address for Correspondence
*Post Graduate Student, **Professor & Head, Mechanical Engineering, JSPM’S RSCOE,
Pune (MS), India-411033

ABSTRACT
This paper tries present with a comparative study of single stage and two stage turbo charging and proposed experimental set up to validate application of a two stage turbocharger for lowering down the engine displacement as a means to enhance specific fuel consumption and reduced CO2 emission. Discussing turbo charger matching for two stage arrangement is another aim. An effort is also made to have an overview of a hybrid pressure boosting system. The paper also advocates reduction in pumping losses, improvement in mechanical efficiency and improved in-cylinder turbulence with the help of downsizing proposed earlier.

KEYWORDS: Reduced NOX emission two stage turbo charging, Turbocharger matching, Boost control alternatives.

I. INTRODUCTION

Over the years, raising man kind’s standard of life increased the concentration of CO2, one of the major contributors of greenhouse effect, by 36% globally since the Industrial Revolution, which has emerged with wide usage of fossil fuels [1]. The major source of this can be cited as transportation. Enhancing the fuel consumption of IC Engines mounted on automobiles will surely help in resolving this issue to a great extent. This research paper will concentrate on reducing the displacement of engine and also reducing the number of cylinder an engine uses, so as to result in to lesser emissions of CO2. All in all it can be achieved by making the engine run at higher loads accompanied by pressure boosting using a turbo charger [2-11]. Fontanesi S. et al. [3] has discussed how a 1.8 l engine coupled with a two stage turbo charger can result in to improvement in fuel consumption by 24% when compared with a 2.5 l engine. Further, Wenger U.et al. [5] has pointed out availability of better driving conditions due to reduction in engine displacement and subsequent reduction in overall weight of vehicle.

The studies carried out by various eminent scholars [2-11] show cases some important major advantageous contributions of a turbocharger like lower pumping losses on account of less volume being swept on each engine revolution and also due to usage of waste exhaust heat to force the piston under boosting. Useful work is done during induction due to turbo charging. Also reduced wear results in greater mechanical efficiency. Apart from this, the swirl pattern in the cylinder improves due to increased intake pressure, which further enhances combustion. It is also seen that brake specific fuel consumption reduces at idle and part load conditions. Following points can be counted on negative side of turbo-charger. Like, great skill is required in matching of a turbocharger as it is quite a tedious job. Also, at low speeds the torque produced by a turbocharged engine is much lower than that of a naturally aspirated engine. More over the transient performance of a turbocharged engine is slower compared with normal engine as centrifugal compressor has to attain substantial rotational speed and hence fails to produce usable boost instantly [12,13]. These problems become even worse when it comes to diesel engines with smoke limiting fuel arrangements. In order to overcome these problems associated with turbo charging, many methods are suggested like inertia reduction, aerodynamics and bearing improvements [14], variable geometry on both compressor and turbine sides [15], and electrically assisted turbo-charger [16], also for the charging system set up such as twin turbo system [17], sequential system [18], and dual-stage system [19]. Apart from this, another option is made available in the form of usage of secondary charging systems like positive displacement charge and electrical compressor are used either alone [20-22] or along with Turbocharger [16, 23, 24].

II. SINGLE STAGE Vs DUAL STAGE TURBO CHARGING

A common problem is always associated with single stage turbo charged engine that it has a poor transient response. A recent development in single stage turbo charging is to observe a variable geometry turbine. Its primary objective is to reduce turbo-lag. These variable geometry systems are useful for both SI and CI engines. But as SI engines are having high exhaust gas temperature, variable geometry solution is not that much suitable for SI engines [25]. A lot of research has been done in the area of Variable Geometry Turbines [15, 25-28] but still the problem of poor transient response at lower speed could not be resolved.

Figure 1. Booster Pressure Comparison

|Green : Single Stage , Blue: Two Stage| [26]|

Against this, various advantages were found over single stage turbo charging if replaced with dual stage system. A twin turbo charging system results in to enhanced transient response due to the lower inertia if we compare it with a single turbo charger system meant for same volume. However, the improvement is much more significant with sequential turbo charging since only one turbocharger
is used at low engine speed instead of two. Okamoto et al. [18] showed that by using a new sequential twin turbocharger, maximum boost pressure can be achieved 30% and subsequently engine power can be hiked by 25%. Apart from this, when it comes to diesel engines, it’s found that the specific power output readily increases, that too, for a wide speed range, on account of very high pressure boost when compared to single stage. [3, 10, 29].

III. TURBO-CHARGER MATCHING

Turbocharger matching is meant by selection of a compressor and turbine combination in order to meet the required boosting pertaining to prescribed band of engine operations. An effort is also done to optimize this combination. It’s expected that the compressor so chosen should offer maximum possible efficiency during crucial engine operation zones while engine running at full load.

Various advancements like Common Rail Injection, Variable Geometry Turbine, multiple injection systems has proven their ability to almost nullify various problems discussed earlier. But again the problem of lower power development zones still persists. One has to come across the dual stage turbo charging option in order to bless the diesel engines with greater specific power because the air supplied to engine remains the only limiting parameter.

Let it be numerous advantages a two stage turbo charger offers against single stage, but lot many different complexities are associated with two stage turbo chargers when it comes to its matching. Surprisingly, matching is discussed as a procedure of Trial and Error in most of the studies published on dual stage turbo charger [10, 30] but its also found that the matching should be worked out precisely as it directly affects engine performance. Again a non precise and trial and error nature of matching will surely lead to lower power output at low speeds for partly loaded engines. The principal reason behind this is availability of a very low pressure ratio after every stage in case of a two stage turbo charger when compared to single stage [31].

Benson et al. [32] tried to match a two stage turbo charger by using an externally blown air supply but the engine used by them during this study did not have that much fidelity, leading their studies to limited success.

Today also, two-stage turbocharger used with fixed geometry turbines needs to be improved a lot if used for replacing a heavy volume engine in transient conditions and for low speed conditions.

In his study, Byungchan Lee [33] first chosen a thermodynamic zero dimensional model which was developed by Assanis [34] and then validated the facts laid by Assanis against various engines like Locomotive engines [35]. A Dynamics oriented sub modular system was added to analyse the performance of engine against transient conditions depending upon crank rotations [36]. Lee again added a two stage pressure boosting system to almalysate the interface of booster and the engine. However Lee has to opt for a simulation oriented proceeding than actual experimentation as the said model was again in need of highly precise matching and tuning.

In this simulation, various models like Air Filter Model, Turbocharger Model, Inlet/Exhaust Manifold Model, In-cylinder Process Model, Valve Flow, Injection Control, and Vehicle System Model were formed and studied. But one has to always keep in mind that the basic flaw associated with a zero-dimensional model that it cannot convey or predict the emission oriented end effects and also gas dynamics related issues and hence Cylinder to cylinder alterations can’t be analysed with this engine model. However following important facts should be noted.

- In this study the convective heat transfer coefficient is calculated from Nusselt-Reynolds correlation for a steady flow through a circular channel which is of turbulent nature following the assumption of Characteristic Flow Velocity [34].
- The duration of delay period is governed by Mean Cylinder Gas Temperature and pressure and given by an empirical relation by Arrhenius [34].
- The base for injection control module in this Study depends upon data from M/S International [35] and counts on engine speed, manifold pressure and fuel to be injected with its timing.

In order to match a dual stage turbo charger a systematic approach is to be floated. The pressure and temperature at the end of first stage is unknown even though overall pressure ratio is known. Therefore it is necessary to assume pressure ratios at the end of each compressor with constant overall pressure ratio. With this we can calculate pressure and temperature at the inlet and exit of the turbochargers and then we can calculate further the pressure ratio and corrected mass flow for turbocharger set. A set of guidelines is roughly suggested by Janota [31] which conveys that dividing the work evenly for each stage keeps the overall efficiency optimum. But the value of pressure ratio between 1.4 to 1.7 does not affect the overall efficiency. Hence it is clear that the said guide lines are not adequate to calculate the optimum pressure ratio for every stage.

Figure 2. A typical Dual Stage Turbocharger Configuration[34]

IV. BOOST CONTROL ALTERNATIVES

An overview of boost control alternatives is taken herewith. Though various pressure enhancement options are available, a provision of bypass valve and a waste gate is made. The matching process is worked out by keeping the valves non functioning. The performance points on compressor maps is studied and some adjustments are done with high pressure and low pressure turbocharger. The said
provision of bypass valve and a waste gate is made to control the power flow for high and low pressure turbines. Also a limit is set over actual cylinder pressure against its mechanical strength.

Apart from this early and late closure of inlet valve is also considered as pressure boosting options which also result in to enhanced part load performance [36,37] in case of SI engines as pumping losses on account of throttling are reduced. Some of the studies have also demonstrated the abilities of this early and late closure of inlet valve technology to improve part load fuel economy for SI engines [38-43]. In case of CI engines this technology is exploited to reduce NOx emissions [30, 44] and to improve fuel economy [45]. However certain disadvantages are encountered with early closure of inlet valve as far as combustion is considered. A study has explored effect of such technology in a fully variable valve train research engine.

V. SUBSEQUENT EMISSION CONTROL

The results show that NOx emissions are almost a linear decreasing function of the pressure ratio and specific fuel consumption (be) shows clear minimum for certain configuration if engine power, peak pressure, air fuel equivalence ratio and exhaust gas temperature is kept constant for a medium speed diesel engine equipped with two stage turbo charger [46,47,48,49]. Also Smoke Number SN is reduced with this remedial solution. Another study [50] how NOx emissions and PM emissions are reduced by installing a two stage turbo charger with a 12 liter 390 kW diesel engine. Smoke number is also reduced in two stage turbocharger against single stage [26].

VI. CONCLUSIVE REMARK

It’s now clear that two stage turbo charger along with boost control options is to be surely preferred over single stage on account of better fuel economy, better part load efficiency and reduced emissions. However matching of this two stage turbo charger is quite a complex process and requires lot of skill and also trial and error nature of this process is another problem associated with this matching. A comprehensive study has to be done to develop more trustworthy and easier matching procedure to exploit the benefits of two stage turbocharger to the maximum extent.

REFERENCES

Bulbole et al., International Journal of Advanced Engineering Research and Studies  E-ISSN2249–8974

46. Neuschwander, P., Thiele, M.and Haueisen, V., 2010, New turbochargers for more powerful engines running under stricter emissions regimes, 26th CIMAC World Congress in Bergen (N)
47. Wink, Ch. and Hallbäck, B., 2007, Utilisation of 2-stage turbo charging as an emission reduction mean on a Wartsila 4-stroke medium-speed diesel engine, 25th CIMAC World Congress in Vienna, Austria
49. Ennio Codan, Christoph Mathey, Adrian Retting, 2010, 2-Stage Turbocharging – lexiability for Engine Optimisation, 26th CIMAC World Congress in Bergen (N)