DESIGN AND DEVELOPMENT OF DYNAMOMETER CHARGERED TURBOCHARGER

[1]SESHAN P.S, [2]NARENDRAN K, [3]KATHIGEYAN.K

[1,2]Mechanical Engineering, S K R Engineering College, Chennai,India
[3]Mechanical Engineering, Jawahar Engineering College, Chennai,India

Abstract—Turbocharger is an integral component of the engine where the performance can be increased drastically. A turbocharger compresses the air so that more oxygen flows into the combustion chambe. During the start of the engine, the turbocharger experiences a Turbo Lag, this lag can be elimated by triggering the rotating shaft using a dynamometer. This overcomes the initial lag and boost the engine at the initial level, thus by creating a constant efficiency.

Keywords—Turbocharger, Turbolag, Dynamometer charged.

I. INTRODUCTION

In line with efforts to conserdve the global environment, regulatory authorities around the world have steadily continued to tighten their control of automobile emissions and fuel consumption. The performance of an internal combustion engine can be increased by adding turbo charging. A turbocharger compresses the air so that more oxygen flows into the combustion chamber. In this way, more fuel is burned and the power output of the engine increases accordingly. The turbocharger is driven by exhaust gas, which makes turbocharged diesel engines very efficient. Turbochargers are also being increasingly applied in gasoline engines as a means to downsize the engines, lighten their weights, and improve their efficiency. Generally, exhaust gas from the main diesel engine is directed entirely to the turbocharger turbine. The induced force drives a compressor in a configuration in which air for combustion is compressed and supplied to the engine by the turbocharger. Accordingly, the efficiency of the turbocharger is measured by the ratio of the adiabatic heat drop of the turbine to the adiabatic compressive work of the compressor.

A process of supplying the air to diesel engine is called as turbo charging. Turbo charger works on the principle of gas power cycles (i.e. similar to gas turbine engine) there are two main components in turbo charger which is compressor unit and turbine unit. The compressor unit is of centrifugal type flow of air to the compressor acts radically through the impeller to diffuser.

II THEORY

2.1 Forced Induction

All naturally aspirated engines use the down stroke of the piston to create a low pressure area, drawing in the air and fuel mixture into the cylinder. The volumetric efficiency varies from engine to engine. Forced induction is when air is forced into the cylinder to increase the volumetric efficiency. The power output of the engine depends upon the amount of air inducted per unit time and the degree of utilization of this air, and the thermal efficiency of the engine.

2.2 Background

Obtaining the maximum engine power output over a wide operating range while meeting emissions, fuel economy, packaging, cost and driveability standards has been objective of most engine development efforts. With the advent of the fuel crisis and the attendant vehicle downsizing programs, the use of forced induction has been a popular method to increase downsized engine power while increasing fuel economy and in essence meeting the strict emission legislation set down. For this comparison all reference has been made to a standard screw type Supercharger and a standard iron turbine type Turbocharger.

2.2.1 Engine Response

The Turbocharger does not reach its maximum efficiency range until high speed and airflows are achieved later in the vehicle acceleration event. The latest Turbochargers with variable geometry housings and ceramic turbines still take four times as long as a positive displacement.

2.2.2 Efficiency

Turbocharger airflow delivery characteristics do not match the requirements of the internal combustion engine because of the volumetric efficiency versus speed difference. Turbochargers only display efficiency over a limited flow range. Turbo systems must be compromised to provide some low speed boost while matching high speed flow requirements. This usually requires waste gating which reduces maximum power. The Supercharger exhibits airflow delivery characteristics very close to the engine requirement. Thus, boost remains almost constant over the total speed range without waste gating or other compromising control systems

2.2.3 Noise And Durability

With Turbocharger driven by exhaust gases turbine noise is nearly eliminated. Durability cycles are affected by the extreme temperatures to which the turbine and housings are subjected, leading to fatigue and inevitable failure. Supercharger noise, along with durability concerns, has been the expressed reservations associated with automotive use. With improved designs and advanced materials noise levels have been reduced considerably.

2.2.4 Lubrication

Turbochargers are subjected to extreme temperatures and in "shut down" situation the oil remaining in the turbine bearing sections will reach coking (burning) temperatures. The carbon build up in the engine’s lubricating system will accelerate the internal wear of the engine and add to the rapid deterioration of the oil. Superchargers can be lubricated by self-contained systems which without the extreme heats experienced by Turbochargers will last for periods well in excess of the engine lubricants.

2.2.5 Aftercooling (Intercooling)

Turbochargers are subject to extreme temperatures, and discharge temperatures need lowering through after coolers if high performance levels approaching that of Superchargers are to be reached. Superchargers do not require after cooling as outlet temperatures rarely exceed 140 degrees C.

2.2.6 Driveability

Unlike a direct coupled Supercharger, performance is only enhanced in proportion to turbine speed. Therefore performance at low speed is limited and a distinct pause is encountered under acceleration known commonly as Turbo lag.

2.2.7 Exhaust Emissions

Turbochargers can be tailored to meet emission levels at normal operating temperatures but suffer on cold starts. Contrary to the heat generated by a Turbo, the exit gases are still low, and results in a longer catalytic light up time on cold starts. This results in unacceptable levels of exhaust emissions at engine start up and legislation is slowly reducing the light up period available which will create problems for Turbochargers.

2.3 Turbo System In Operation

Engine power is proportional to the amount of air and fuel that can get into the cylinders. All things being equal, larger engines flow more air and as such will produce more power. If we want our small engine to perform like a big engine, or simply make our bigger engine produce more power, our ultimate objective is to draw more air into the cylinder.

III. METHODOLOGY

3.1 Improvement Of Transient Behaviour

The main targets in developing combustion engines actually are to improve transient behaviour combined with high output, a wide rpm range with constantly high torque and a reduction of fuel consumption. To achieve these targets there is no way around an adequate turbo charging system. The realisation of a hybrid turbocharger as mild hybrid could represent the ideal solution.

3.2 Challenge

The major problem of all turbocharged combustion engines is their delayed response regarding the mean effective pressure build up at low rpm. With turbochargers, the charging process is only coupled to the internal combustion engine on the thermodynamic level. On the one hand this offers the advantage that the exhaust gas energy can be utilised, on the other hand the disadvantage that depending on the load point in the characteristic field, the turbocharger speeds vary significantly. In case of a load step taking place at low engine speeds (1500 to 2000rpm), only a low enthalpy gradient is available to the turbine for the compressor capacity and power loss.

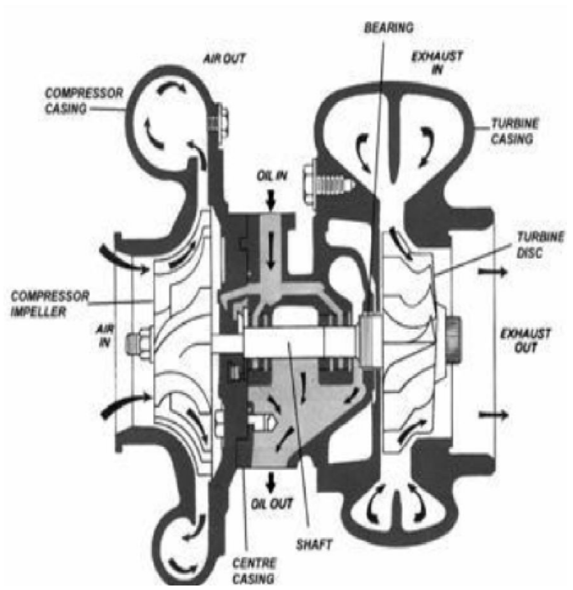
Only the still free performance then serves to the acceleration of the rotor, consisting of turbine wheel, rotor shaft and compressor wheel. In addition, the lower turbine efficiency in the lower map range is another handicap. A consequence of these effects is an only low available power to accelerate the turbocharger to the stationary endpoint. This incomplete charging process again does not only negatively influence the driveability but also the energy consumption as well as the pollutant emissions. Even with modern turbocharged engines, a large portion of the gas escaping in the driving cycle is emitted during dynamic operating phases.

3.3 Approaches

To make turbocharged downsizing engines really attractive to the common, additional measures must be taken to support the turbocharger in transient operation. These should all pursue the same targets increase the energy supply for the turbines in dynamic operation. The most effective means to positively influence the dynamic behaviour of turbocharged engines is to feed the system temporarily with auxiliary power. For more than ten years, the idea is pursued to support the charging process temporarily by the help of electric motors. The basic idea was to decouple the high-speed rotating parts responsible for the delayed response of the thermodynamic function and increase the number of revolutions primarily by the electric motor. Besides the pure electromotive support of the charging pro- cess, such an approach in principle offers the possibility to recuperate energy. Rather than directing the exhaust gas energy via the wastegate unused, by utilising a generator, electric energy can be produced and stored temporarily in an energy storage. In addition, these charging units should be able to be controlled more accurately as a constant speed monitoring takes place. Features such as an active post-cooling, avoid harmonics and over-speeding, recharging for the cold start to reduce emissions etc. represent other possible benefits. Many attempts to realise an electrically assisted hybrid turbocharger failed up to now because the used conventional electric motors have increased the moment of inertia of the rotor group to such an extent that an improvement of the response of the electrically assisted turbocharger could not be reached. The most effective means to positively influence the dynamic behaviour of turbocharged engines is to feed the system temporarily with auxiliary power.

3.4 Turbocharging

The use of turbochargers for boosting charge air in internal combustion engines has been demonstrated as an efficient means for increasing power output and efficiency of the engine. The use of otherwise wasted energy in the exhaust gas of the engine to drive the turbocharger contributes to its efficiency as a boosting device. However, the reliance on exhaust gas contributes to an effect known as “turbo lag” in developing power in the engine for acceleration. Boost provided by the turbocharger is dependent on the exhaust energy.



Consequently, upon demand for immediate power, the addition of fuel to the charge supplied to the engine occurs first with exhaust energy building slowly increasing energy to the turbine of the turbocharger which, in turn, drives to compressor through the interconnecting shaft to provide boost pressure through the turbocharger in a “boot strapping” effect. Turbo lag can be reduced or eliminated through the addition to the turbocharger of an electric motor that can add energy to the spinning rotor group independent of the actual exhaust energy.

The addition of the electric motor allows spin up of the rotor substantially instantaneously to match fuel and boost or the desired power output, with electrical power input being reduced as the exhaust energy becomes sufficient to sustain the necessary level of boost.

By connecting a centrifugal supercharger to a turbine drive wheel and installing it in the exhaust path, the lost engine horsepower is regained to perform other work and the combustion heat energy lost in the engine exhaust (as much as 40% to 50%) can be harnessed to do useful work. This is the concept of a turbocharger.

3.4.1 Turbocharger Design And Operation

A turbocharger consists of two chambers connected by a center housing. The two chambers contain a turbine wheel and a compressor wheel connected by a shaft which passes through the center housing. The exhaust drives the turbine wheel on the left, which is connected to the impeller wheel on the right through a shaft. The bushings that support the shaft are lubricated with engine oil under pressure.

3.4.2 Turbocharger Size And Response Time

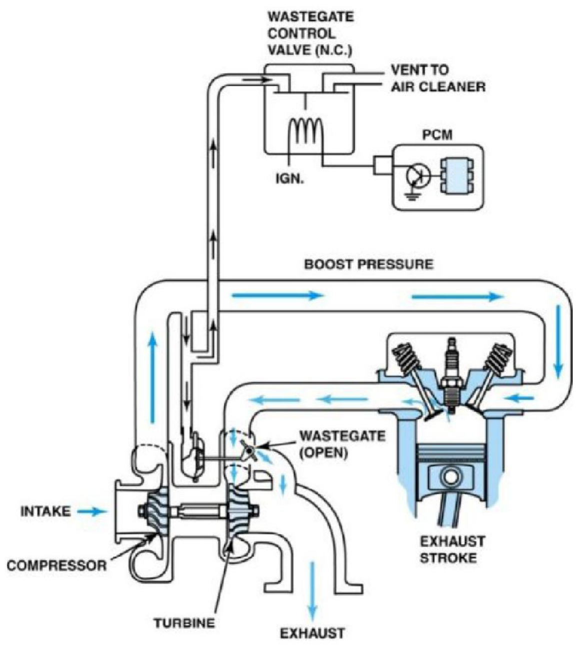
Turbocharger response time is directly related to the size of the turbine and compressor wheels. Small wheels accelerate rapidly; large wheels accelerate slowly. While small wheels would seem to have an advantage over larger ones, they may not have enough airflow capacity for an engine. To minimize turbo lag, the intake and exhaust breathing capacities of an engine must be matched to the exhaust and intake airflow capabilities of the turbocharger.

3.5 Boost Control

3.5.1 Wastegate

Turbochargers uses exhaust gases to increase boost, which causes the engine to make more exhaust gases, which in turn increases the boost from the turbocharger. To prevent over boost and severe engine damage, most turbocharger systems use a wastegate. A wastegate is a valve similar to a door that can open and close.

The wastegate is a bypass valve at the exhaust inlet to the turbine. It allows all exhaust into the turbine, or it can route part of the exhaust past the turbine to the exhaust system.



3.5.2 Relief Valves

A relief valve vents pressurized air from the connecting pipe between the outlet of the turbocharger and the throttle whenever the throttle is closed during boost, such as during shifts.
There are two basic types of relief valves:
Σ Compressor bypass valve or CBV.
Σ Blow-off valve or BOV.

3.6 Electro Turbo Generation

The Energy is lost in several forms. The largest being the heat energy dissipated to the environment via exhaust gases. The EHR system is designed to recover heat energy in the exhaust gases and convert in to useful work for the vehicle. Existing system convert come of the exhaust heat energy in to mechanical energy that is fed back to crank shaft via hydraulic coupling and gear train. The concept of electro turbo generation converts some exhaust heat energy in to electrical energy. The underlying technology is based on integrating compact high speed electrical machines with high performance turbo machinery in various combinations.

IV. EXPERIMENTAL SETUP

4.1 Test Bench

Turbo setup was mounted over a fixture made to withstand the vibrations from the engine test rig. The fixture consists of two parallel legs welded individually. The dynamo set is perfectly kept in axial alignment with the turbine end of the turbo charger. Both the turbine hub end and the dynamo shaft end are connected by means of connector through extended shaft. Both the turbo-dynamo setup was placed over a wooden board, and the dynamo mount is enclosed by sheet metal casing to avoid the direct contact of exhaust gases onto the dynamo. The necessity of providing casing is that higher temperature would reduce the ability of dynamo to develop emf, without any cooling amenities. Extension of shaft was made such that the dynamo is not exposed to elevated temperature emitted via exhaust stream. The connection to engine exhaust terminal was made through reducer coupling, in turn linked to turbocharger by means of coupler which is bolted.

SPECIFICATIONS

4.2 Engine Specification

Type : Single cylinder four stroke water cooled diesel engine
Rated power : 5HP
Rated speed : 1500 rpm
Bore diameter : 80mm
Stroke length : 110 mm
Orifice diameter : 22 mm
Compression ratio : 16.5:1

4.2 Specification Of Turbo Charger

Speed (rpm)	500
Watt	26.00
Voltage	12.00
Ampere	2.2
Resistant temperature	Max 55.2°c
Precaution	Keep 15cm distance

4.3 Experimental Procedure

The main objective of the project is to reduce the turbo lag, so that there is minimization of transient response of forced induction system. The entire test rig is placed over a wooden platform and the turbine inlet port is connected via iron pipe to the engine exhaust pipe. The methodology to implement the reduction of lag was done through two cycles. In first cycle, the turbine is allowed to rotate by exhaust thrust, thereby rotating the dynamo as the shaft is connected between the turbine hub and dynamo shaft. The dynamo begins to produce voltage after reaching rated rpm, which is stored in DC battery. In the second cycle once the engine was turned ON, the turbine would lag inherently to reach desired RPM. In the meantime the battery was switched ON, which rotates the turbine instantly thereby providing initial pick up for the RPM. As the assisted turbo rotates, it requires lesser time than the conventional turbocharger.
From Table below, we could infer that the variation of time (i.e. time reduces) happens with the assistance of dynamo. Measurement of speed of rotating shaft was done through laser tachometer with the sensor strip attached to the shaft. The entire procedure is recorded, and thevideo is sliced to get the specific rpm at intended parameter (time).

V. SPEED AND TIME MEASURMENT

TIME (Sec)	SPEED WITHOUT ELECTRIC ASSISTANCE (RPM)	SPEED WITH ELECTRIC ASSISTANCE (RPM)
1	0	0
2	100	110
3	200	300
4	300	475
5	400	544
6	500	722
7	600	1064
8	700	1070
9	800	-
10	900	-
11	1000	-
12	1070	-

Turbine Speed (rpm)	400
Voltage Developed	3.4

5.1 Voltage Measurment

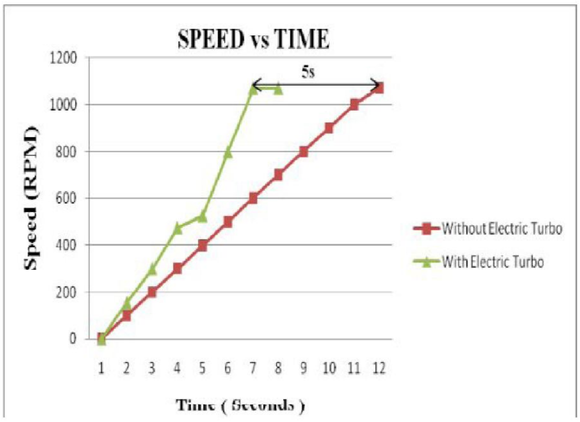
The speed of the turbine blade rotation was reduced by means of providing standoff distance between the exhaust pipe and the turbine inlet port. The developed voltage was measured by mulitmeter, which can be also used as auxiliary power source.

The feasibility of running a DC dynamo by the turbo charger, was checked when the engine was allowed to run at constant speed. From Table 5.4 the output of the dynamo was noted.

5.2 Experimental Data

Power produced by the dynamo,
Power (P) = Voltage x Current
= 3.4 V x 2.2 A
= 7.48 Watt.

*From th*e experiment, the power obtained by connecting the alternator to the turbo charger is 7.48 Watt which is 0.025% of the total power supplied by the fuel. Thus it is obvious that, out of the 40% exhaust losses, 0.06% can be recovered by electro turbo charging in this engine



Transient response of turbocharger (RPM) and time

The above graph compares the transient response of the turbocharger speed and the time taken with and without dynamo assist. The effects of the dynamo assist are noticeable if we look at the values during acceleration the turbocharger took 39 % less time to reach 1070 rpm. The turbine torque became dominant after several seconds of acceleration, leaving the steady differences as shown in Table. The major problem of all turbocharged combustion engines is their delayed response regarding the mean effective pressure build up at low rpm. The most efficient way to improve the dynamic behaviour of turbocharged engine is to feed the system temporarily with auxiliary power at a certain time.

We have experimentally confirmed that the hybrid turbo charger effectively improves engine torque and eliminates turbo lags when applied to automotive engines. The graph compares the transient response of the turbocharger speed and the time taken with and without dynamo assist. The effects of the dynamo assist are noticeable if we look at the values during acceleration the turbocharger took 39 % less time to reach 1070 rpm. The turbine torque became dominant after several seconds of acceleration, leaving the steady differences as shown in Table. The major problem of all turbocharged combustion engines is their delayed response regarding the mean effective pressure build up at low rpm. The most efficient way to improve the dynamic behaviour of turbocharged engine is to feed the system temporarily with auxiliary power at a certain time.

We have experimentally confirmed that the hybrid turbo charger effectively improves engine torque andeliminates turbo lags when applied to automotive engines.

VI. RESULT

In an attempt to explore the possibilities of waste heat recovery in an IC engine, the concept of Electro Turbo generator has been proved by running an alternator coupled to a turbocharger. By the introduction of electro turbo generation, the useful work obtained from the engine has been increased from 19.96% to 20.025%. The above one is a very small quantity, because turbo generation system used here is not specially designed for this engine. By designing an alternator for this engine conditions, the quantity of useful work recovered can be improved. From the Table 6.1 we could infer the segregation of power given and its usage including avoidable losses that occur.

In a small engine this quantity may be of less advantageous. But thinking in a global manner, the energy conserved will be high. At present this idea is in initial stage and is to be analyzed by constructing the appropriate physical system.

SCOPE AND FUTURE WORK

In the future, the following tasks toward the development of an in-vehicle hybrid turbo may be taken. ÿ Establish a technology for ultrahigh-speed motors and inverters that can be realized electrically and thermally based on the specifications for the existing vehicle 24-V battery, expected to be widely adopted in the future. ÿ Establish a method to control the hybrid turbo as part of an optimum system in combination with an engine and exhaust gas after treatment device. ÿ Establish a power supply system comprised of the hybrid turbo charger working effectively with other in-vehicle electrical components.

REFERENCES

[1] J. Cheong et. al., [2000**]** **‘**High Speed Direct Injection (HSDI) Diesel engine’, IEEJ Trans Vol. 25 No. 9 (2000) p.154.

[2] Ibaraki, [2005] S. et al., ‘Turbocharger R & D in MHI’, Journal of the Gas Turbine Society of Japan, Vol. 33 No. 4, p.288.

[3] Nasser et. al., [2009] **‘**Effect of intercooler at multicylinder engine performance for operation at a constant speed’, IEEJ Trans Vol. 15 No. 12 (2009) p.854.

[4] Panting et. al., [2001] ‘Turbine resizing and reoptimizing valve timing’ IEEJ Trans Trans Vol. 421 No. 11 (2001) p.356

[5] Rakopoulos et. al., [2004] **‘**Computer analysis for studying availability performance of a turbocharged

diesel engine', 3rd International Conference on Turbochargers and Turbo charging, Paper, p.147.

[6] Takahashi, [1994] I. et al., 'A Super High Speed PM Motor Drive System by a Quasi-Current Source Inverter', Industry Applications, IEEE Transactions, Vol. 30 Issue p. 683.

[7] Takata.Y.et al., [2005] 'Motor Drive for Turbo charger', IEEJ Trans. IA. Vol. 125 No. 9 p.854.

[8] Yamashita, [2007] Y. et al.'Development of Electrically Assisted Turbocharger for Diesel Engine', 8th International Conference on Turbochargers and Turbo charging, Paper, p.147

★★★