Turbocharger Lag Mitigation System

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Abstract. A Turbocharger mitigation system was designed for vehicular operations and simulated in lab conditions. In production cars, a huge loss of power is noticed under 1500 rpm which is termed as “turbo-lag”. The effects of turbo lag include increased fuel consumption, lesser efficiency, brake power loss and more emissions. A complete analysis of the existing system was done and the parameters were measured for a wide range of engine rpm. A servo motor actuation system was mated with the turbocharger. The control algorithm and principles were programmed in Arduino software. After successful implementation, the results were compared with the previous setup in MS Excel software.

Keywords: Turbocharger, turbo-lag, efficiency, fuel consumption

1. Introduction

With the objective of reducing the turbo lag of a forced induction system, we had to get the parameters affecting it. Hence an experimental study was conducted on the test rig without the fitment of turbocharger. Later the turbocharger was fitted on the test rig with necessary precautions. The same test was run again with the fitment and the system designed by us. The parameters were kept constant and the result was tabulated in excel. The project provides a deeper understanding of forced induction systems and the engineering limitations associated with it. In piston engines, intake gases are pulled by the downward stroke of the piston creating a low pressure area. Volumetric efficiency is the amount of air intake compared to theoretical amount if the engine could maintain atmospheric pressure. The turbocharger improves an engine’s volumetric efficiency by increasing density of the intake air. The turbocharger’s compressor draws natural air and compresses it before it enters into the intake manifold at increased pressure. The mass of air increases on each intake stroke as a result.

Turbo lag is the time required to change power output in response to a throttle change which slows throttle response when accelerating as compared to a naturally aspirated engine. This occurs due to
time required for the exhaust process and turbocharger to generate the boost required. Turbo lag is basically produced due to inertia, friction and compressor load. If engine speed is below a turbocharger's boost threshold rpm then the time needed for the vehicle to build speed and rpm could be considerable. Once the vehicle reaches sufficient speed to provide the required rpm to reach boost threshold, there will be a far shorter delay while the turbo itself builds rotational energy and transitions to positive boost, only this last part of the delay in achieving positive boost is the turbo lag.

**The Centre Hub Rotating Assembly** - The centre hub rotating assembly (CHRA) with extra technology of waste gate actuators and blow off valves houses the shaft that connects the compressor impeller and turbine. It also must contain a bearing system to suspend the shaft, allowing it to rotate at very high speed with minimal friction. The CHRA should be water cooled by having an entry and exit point for engine coolant (in modern applications). CHRA is used to avoid oil coking from the extreme heat in the turbine. The development of air-foil bearings removed this risk.

### 2. Experimental Setup

The engine used is Mahindra twin cylinder CRDi diesel engine which is a direct injection four stroke supported by water radiator horizontal type engine.

**Table 1. Engine specifications**

| Parameters         | Specifications          |
|--------------------|-------------------------|
| No. Of Cylinders   | 2                       |
| No. Of Strokes     | 4                       |
| Fuel               | Diesel                  |
| Rated Power        | 18.4 kW @ 3600 rpm      |
| Bore               | 83 mm                   |
| Stroke             | 84 mm                   |
| Compression Ratio  | 18.5:1                  |

**Table 2. Dynamometer specifications**

| Parameters       | Specifications          |
|------------------|-------------------------|
| Type             | Hydraulic Dynamometer   |
| Arm Length       | 200 mm                  |
| Fuel             | Diesel                  |

**Table 3. Turbocharger specifications**

| Parameters       | Specifications          |
|------------------|-------------------------|
| OEM Part No      | KP-35                   |
| Used in          | Maxoo Light truck       |
Natural & Forced Induction Mode
The Engine is run without turbocharger fitment. The flow of air is from the air filter to the cylinder head. The air is inducted into the cylinder during the intake stroke followed by compression and combustion. Finally the air is expelled out through the exhaust. The hot exhaust gases drive the turbine of the exhaust side. As the gas is hot and expanding during the process, it does work ON the system. The co-axial impeller acts as a pump in the process and pushes more air for induction hence reducing cylinder pumping losses. An oil supply is provided to supply the bearings with fresh, cool oil. Latest advancements include an EGR System, Intercooler for efficient practical operation.

Turbo Lag Mitigation System
The system incorporates a stepper motor control in place of a vacuum assisted solenoid actuator. The main objective is to cut off the supply of exhaust gases to the turbocharger hence isolating the forced induction system. As exhaust gases can move freely, there is no backpressure. Another duct was provided from the inlet side to the cylinder head to facilitate the bypassing of air from the turbocharger. Once the engine rpm is below 1500, the stepper motor will actuate the lever to shut off the turbo. It activates the turbocharger above 1500 rpm only.

Figure 1. The arduino board with the circuit

3. Result and Discussions
For the engine specifications and turbocharger specifications, two types of tests have been carried out. One type is at low speed rpm, the engine is compared with turbocharger mitigation system and without using it. Another type is at high speed rpm, the engine is compared with turbocharger mitigation system and without using it. The observed results and graphs have been plotted and showed below.

For the type I of low speed is taken at 2000 rpm. Here the graphs are plotted without turbocharger showing the load, time taken for 10cc of fuel consumption and mean height of manometric fluid over the whole operation range. It has been observed that the load increases linearly whereas time taken for 10cc of fuel consumption decreases. Also mean height of manometric fluid decreases first, reflecting a surge in induction and then remains constant.
It is inferred that at low speed of 2000 rpm, volumetric efficiency is more with turbocharger whereas it is less without turbocharger. Also, the improvement in Volumetric efficiency is observed as 3.84%.

For the type II of high speed is taken at 3500 rpm. Here the graphs are plotted without turbocharger showing the load, time taken for 10cc of fuel consumption and mean height of manometric fluid over the whole operation range. It has been observed that the load increases linearly whereas time taken for 10cc of fuel consumption decreases. Also mean height of manometric fluid decreases first, reflecting a larger surge in induction and then remains constant.

**Figure 2**: Load, hm, time taken(tt) graph for 2000 rpm (w/o turbo)

**Figure 3**: Load, hm, time taken graph for 2000 rpm (w/ turbo)
It is inferred that at high speed of 3500 rpm, volumetric efficiency is more with turbocharger whereas it is less without turbocharger. Also, the improvement in volumetric efficiency is observed as 2.10%.

4. Conclusion
A possible solution to eliminate the lag caused by a turbocharger at lower rpm is the aim of the work carried out. From the experimental results a few findings are summarized as follows. A volumetric efficiency improvement of 2.1% to 3.84% can be achieved using the existing stepper motor algorithm. With optimum utilization of power, engine emissions can be reduced. The smaller the engine size, the lesser the need of a turbocharger is felt. The use of turbocharger can be eliminated during typical urban traffic of speeds less than 20km/hr. The use of turbocharger is detrimental to the engine at low operating rpms and vehicle speed as it generates more particulate matter emissions and HCs.
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