Turbocharger wastegate tolerance resolution

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ABSTRACT

This paper examines the introduction of a new technology in the manufacturing environment of turbochargers and addresses two central questions. First, how can the proto shop introducing new process technology deal with the change rapidly and smoothly? Further, what benefits the organization gains to enable a plant to respond positively to the change?. This research examined a project where new testing and calibration technology is introduced. Project was undertaken in plants in Cummins Turbo Technologies, MP. In comparing the different process across assembly and proto shop, performance is measured by various factors such as startup time and operating time, set-up time etc. There is a significant portion in the performance gap which can be explained by differences in the way the available mechanisms and the new implemented technology approach the problem. The aim of this paper is to understand and compare the methods used to calibrate the wastegate in turbochargers, the methods discussed are laser guided wastegate setting used in the assembly lines and the manual dial gauge method used in the prototyping department.

Keywords—turbochargers; actuator; wastegate; wastegated turbochargers

1. INTRODUCTION

Turbocharging is an integral component of the engine design concept. It shapes the characteristics of the engine more than almost any other system, as it affects its economy, dynamics and emission characteristics this is why turbocharging is one of key technology to enhance engine performance. Cummins Inc. has a tradition of maintaining the expertise for developing and producing its turbochargers in-house. Turbochargers are purchased for engine designs in which synergy effects with the commercial vehicles sector can be used,[1]

Due to its in-house development and production of turbochargers, Cummins is in a position to meet customer demands for highly responsive and powerful engines. It matches the turbocharging system to the engine so that it delivers reliable high performance across the entire range of engine specifications, from sea level to an altitude of 4,000 meters, and from low to extremely high ambient temperatures. As its turbochargers are configured specifically to meet the engine specifications, they are easily integrated into the overall engine package[2]. This makes the engines very compact — a decisive advantage in applications where installation space is at a premium

The ever increasing government regulation of emissions and driver demands for fuel economy and drivability emphasize the need for advanced engine technology and control. Boosting of engine intake pressure is being proposed as a possible solution to reducing CO\textsubscript{2} emission levels and improving the fuel economy of the engine. The torque developed by a conventional gasoline engine is proportional to the air that is supplied to the cylinders. The density of air entering a boosted engine is higher than that for a naturally aspirated engine, hence for the same maximum
power, a boosted engine is smaller in size. In automotive applications, operating conditions vary within a wide range, which can lead to inadequate boost at low speed and loads, while creating an over-boost situation at high speed and loads. The amount of boost delivered by a turbocharger is typically controlled by a wastegate. Thus the advantages of boosting are accompanied by an increase in complexity of the control design and calibration.

This brings the wastegate design and calibration to the front of the priority for turbocharger manufacturers [3]. This project deals with the streamlining of the wastegate setting in the prototyping phase, such that the process becomes fast and more accurate while being simple enough for a layman to understand and use. At the end of the paper a new method of wastegate setting is implemented in the Protoshop which would help accomplish the above set goals and that is compared with the pre-determined method used for the same process.

2. WORKING OF TURBOCHARGER, WASTEGATE AND ACTUATORS

**Turbochargers**

Turbochargers are centrifugal compressors driven by an exhaust gas turbine and employed in engines to boost the charge air pressure. Turbocharger performance influences all important engine parameters, such as fuel economy, power, and emissions [3]. In the simplest turbocharger design, the turbine and compressor geometry are fixed and the boost pressure is entirely determined by the exhaust flow. An exhaust side bypass, or wastegate, is a common means of achieving better boost pressure control with fixed geometry turbochargers. The wastegate is usually built into the turbine side of the turbocharger. Pressurized pneumatic wastegate actuation has been common, but vacuum actuation and electric actuation is now being developed to be used in newer designs. [4]

**Wastegate Actuators**

Wastegate actuators come in a variety of designs for different applications. While pneumatic actuation is most common, some newer designs are entirely electrically actuated. Basic pneumatic actuators consist of a pressurized air capsule. They directly sense compressor discharge pressure and are designed to open when the intake manifold reaches a set pressure. The force generated by the air pressure depresses a preloaded actuator spring at the designed pressure to open the bypass valve. Valve opening can be adjusted by changing the preload in the actuator by changing the length of the spring. The motion of the pressurized pneumatic actuator is entirely dependent on compressor discharge pressure to open. This makes opening them possible only when sufficient boost pressure is available, i.e., at relatively high load. Wastegate control strategies allow active boost control over a wide range of engine operating conditions. This can be achieved with vacuum operated actuators to drive the wastegate and decouple its motion from the intake manifold pressure using pre-defined pressures and limits. [5]

**Active wastegate strategy**

An active wastegate strategy could be used over an engine speed/load map to improve fuel efficiency while providing good engine dynamic response. At low engine speeds and low to medium loads, the wastegate valve is closed while at all low load conditions it is open. At mid- to high speeds and mid- to high loads, the wastegate valve is controlled as needed to prevent turbocharger over-speeding and avoid excessive boost pressure.
WASTEGATE FUNCTION AND CONTROL

Wastegates are simply a valve that allows some of the exhaust gas to pass directly from the exhaust manifold to the exhaust pipe.

- Allows some shaping of boost curve & hence air fuel ratio
- Reduces turbo speed
- Reduces peak cylinder temperatures & hence NOx

In the past the function of a wastegate was to bypass a small amount of exhaust gas. This would be to bring the turbo speed down at rated conditions to acceptable levels. Both reducing the potential for LCF & HCF failures & or increasing altitude capability of the turbocharger. Typically, today we would fit smaller turbine housing in a wastegate match and hence use the wastegate to effectively improve the torque/particulates at peak torque giving a cleaner & better engine to drive.
WASTEGATE SETTING MANUAL PROCESS

In the previously explained modules it can be easily interpreted the need of wastegate setting done in a turbocharger. In Cummins Turbo Technologies there are two prominent methods use to set the wastegate actuator. Each of the methods along with their merits and demerits are explained below.

Method

- The wastegate setting using the manual method is a time-tested method this requires very few tools mainly a dial gauge mounted on a movable arm, a magnetic stand for clamping the turbocharger and a steady supply of metered air.

- The turbocharger is mounted on the stand clamped onto it, such that the side facing the worker contains the actuator and the wastegate valve

- The air supply is then added to the actuator, the dial gauge is then positioned such as that it is touching the endlink of the actuator as seen in the Fig. 3

- The Dial gauge is then set to zero and the air supply is turned on.

- The check pressure and the boost pressure are then set according to the requirement and then the locknut connecting the endlink to the actuator red is tightened so as to finalize the position of the wastegate

![Fig. 3: Dial Gauge placed in position connecting the endlink of the actuator](image)

Benefits of Wastegate setting using manual Process

The main benefit that can be derived from this process is the level of accuracy that is maintained and obtained by using the manual method. [6] The level of accuracy depends on the least count of the Dial Gauge for this project all the manual readings were taken using Mitutoyo Digital dial gage which has a least count of .001mm[8]. Using manual method the level of accuracy that can be maintained is within 10mm.[8]

Demerits

There are quite a few drawbacks of using a manual method for wastegate setting in a plant the major one is the amount of time taken to set one turbocharger. To set one turbocharger as per the
requirement of the customer it takes an average of 20mins [9] not including the set-up time which can vary from user to user varying from 10 minutes to 15 minutes. Another major drawback of using manual method is the machine capability, this is a contributing factor because the manual wastegate setting that is being described now is exclusively used in the prototyping department only, while for the mass manufacturing in the assembly line a laser guided automated system is used, this automated system is capable of very high speeds at the cost of expanded tolerance limits. Because of this discrepancy between the protoshop and the assembly line the production is affected.

LASER GUIDED WASTEGATE SETTING RIG
Laser guided wastegate setting has been used since early 2000’s this method is specifically developed for the mass production of turbochargers the laser guide can set a turbo charger in less than a minute [10] which is drastically low when compared to its counterpart.

Method
The use of laser guided rig for turbo charger wastegate setting is very simple and relatively less time consuming than the manual method the process is as follows

- Set-up the turbocharger on the rig
- Connect the pneumatic input air hose to the actuator of the turbocharger as shown in Fig. 4 (a)
- Connect the wastegate laser displacement sensor on the top of the actuator as shown in Fig. 4 (b)
- Connect the wastegate displacement sensor flag to the bottom of the actuator rod as shown in Fig. 4 (c)
- Select the type of the turbochargers from the list of turbochargers in the program of manually input the pressure required.
- Run the program, the wastegate setting will be done automatically, remove the air hose and tighten the lock nut
Fig. 4: Method of doing wastegate setting of a turbocharger using a laser guided rig

**Merits**

The main idea behind developing a laser guided wastegate setting rig was to make it assembly line ready, the laser guided rig is capable of setting a turbocharger in less than a minute [10], which make it enormously faster than the manual wastegate setting method.

Another merit of this method is the reliability and repeatability of the laser guided rig. The rig needs minimum human interaction and this makes the outcome more predictable each and every time, this machine is also not affect by the change in operator which is a crucial point for the plant as it operates on a rotating 3 shift schedule, which means that the machine is run by at least 3 different operators every day and still provided consistent results and within the tolerances set by the administrator.[11]

**Demerits**

Being an automated system the rig has some drawbacks such as it requires regular maintenance and regular updates, the operator need to be thoroughly trained to operate this machinery and to maximize its potential, if the operator is not properly trained the machine output is reduced and its efficiency declines. [11]

**COMPARISON**

To compare the either defined methods in the paper to determine which is more suitable to the needs of the plant a comparative study was done

**CONCLUSION**

This paper has analyzed the success of new process introduced in a single technology-based company. Analysis suggested that observed differences in performance can be traced, in the short run, to underlying differences in the way the problem is approached. The response mechanisms Identified -- set-up time, function time, functional accuracy was shown to support improved project performance in terms of startup time and operating improvement. Project in protoshop and assembly differed in their limitations to use these mechanisms in dealing with challenges occurring during new technology introduction, which contributed to different levels of success with new process technology. More importantly, differences at the implementation level have been seen in both the processes. Based on this evidence, the paper can argue that the accuracy level is although the most important aspect of system design the customer requirement are easily obtained by using the laser RIG This study identified related problems of the difference that the protoshop responds to new method of wastegate setting, like challenge of technological change. It can be concluded that the laser guided machine is better suited for the protoshop department when compared to the manual wastegate setting process because it is a time-consuming process which gives a streamlined output compared to the assembly line repeatedly and steadily. Although the tolerance limit of the laser guided rig is wider than the manual process it is still a better fit because the operators and engineers both can commit the outcomes of mass production based on the output generated during assembly process.
REFERENCES


