International Journal of Engineering Research & Management Technology
ISSN: 2348-4039
March-April-2019 Volume 6, Issue-2
Email: editor@ijermt.org www.ijermt.org

STUDY OF METTALURGICAL PROPERTIES OF TURBOCHARGER COMPONENTS SUCH AS TURBINE CASINGS, TURBINE ROTOR BLADES, COMPRESSOR WHEEL AND SUGGESTIONS FOR IMPROVEMENTS

Banshidhara Mallik.
Associate professor

Dr. Satyabrata Pattnaik
Group MD. Dalwin Marine (MNC). In India, Mumbai, Visakhapatnam.

ABSTRACT:

The angle of the blade's influence on the flow field of the turbine wheel is being researched as part of an investigation into the performance of a turbocharger that uses an exhaust gas turbine on diesel engines. This compressor is turbine powered and is used to increase the air flow rate going into the internal combustion engine. Analysis was done on the angle of the blades on the turbine wheel. utilizing the theory of computational fluid dynamics, often known as CFD. How the different blade angles of the turbine wheel are responsible for optimizing the flow field along the blade, which in turn optimizes the pressure and velocity. The study of the blade angle is carried out in order to get an understanding of the flow behavior and to minimize the impacts of the blade angle. In this article, we analyze the flow field along the blade passage of the turbine wheel for the turbocharger. Additionally, we explore the influence flow field has at various blade angles for the turbine wheel output blade angle, which are = 650, 450, and 350.

Keywords: *Turbocharger, Turbine blade, Compressor.*

INTRODUCTION:

The first person to design a machine was probably attempting to gain the most benefit possible from the power of the machine or figure out how to profit from unused energy and save costs by reducing the influence of friction and any other phenomena that caused a lag in the performance of the machine. When looking at the history of turbocharging, one might really go as far back as the late 1800s to the German designer Gottlieb Daimler, or one could even go as far back as 1896 to Rudolf Diesel, who is credited with creating the first mechanical supercharger. In any case, for the sake of continuing that conversation, we are going to proceed with Swiss engineer Dr. Alfred Buchi. The earliest patent for a viable turbocharger, which was a supercharger powered by pulses of exhaust gas, was granted to Buchi in the year 1905. In 1910, General Electric embarked on the process of developing turbochargers. In 1915, Dr. Alfred Buchi, who was working as the head engineer for the research department of Sulzer Brothers at the time, conceived of and created the first prototype of a turbocharged diesel engine. However, there was not a great deal of success with it. It was not successful enough to maintain the appropriate amount of boost energy.1918 was yet another pivotal year, and it can be considered the watershed year for turbocharging in the aircraft industry. In this year, a General Electric engineer by the name of Dr. Sanford Moss brought a 350-horsepower engine to the summit of Pike's Peak in Colorado. And there, at an altitude of 14,109 feet on the second-highest mountain peak in Colorado, Moss was able to increase the power output of that engine to 356 horsepower. The year 1920 was also a pivotal one in the long-running history of turbocharging. A turbocharged 12-cylinder Liberty engine was installed in a biplane manufactured by LaPere and used for altitude research. Oddly enough, they decided to utilize this aircraft because they believed it would be less likely to break up in the event of a severe pull out or a protracted fall from altitude.

Lt. John Macready, a young man, was selected to pilot the aircraft and given that responsibility. He managed to get it as high as 33,113 feet! Macready did not experience any disruption due to the altitude. From 1917 to 1923, he conducted research on turbochargers, during which time he rose to prominence as one of the world's most proficient high-altitude aviators. He was able to reach a maximum altitude of around 40,800 feet with his open cockpit plane. In addition, the date was September 28th, 1921. In the late 1980s and early 1990s, the Grob Strato 2C achieved a height of 54,574 feet, which resulted in it unofficially setting a record for human piston-powered flight. This airplane could not be replicated in any way. With a span of 185 feet, its all-composite wing was the world's biggest all-composite wing ever built. The aircraft was developed to carry out missions such as communications monitoring, geo-physical analysis, weather and pollution observation, and other similar tasks. In 1986, the Boeing Condor set a new record for the highest height achieved by an unmanned aircraft. Motors is 66,980 feet in length. The primary reason for contemplating the development of the turbocharger was the realization that the higher an airplane flies above the surface of the water, the less oxygen there will be. This is what we need in the combustion process, so there must be a solution until the turbocharger was invented, and after turbo used in aircraft also used with the car to increase the power of engine and become small engine with high power to decrease the volume of engine in a car to be lightweight and fast.

Increase the air flow rate into the internal combustion engine utilizing the turbine-driven compressor. Compressing the air and increasing the volume of air that flows into the cylinders of an internal combustion engine are the means by which this goal may be attained. A turbine provides power to the compressor by first extracting energy from the exhaust gas produced by an internal combustion engine and then converting that energy into shaft power. Because the drive shaft of the engine is not being used to power the compressor, the arrangements are in their optimal form. The turbine in a turbocharger makes use of the energy in the exhaust gas that would otherwise be wasted in a naturally aspirated engine. This makes turbochargers more efficient than naturally aspirated engines. for the turbocharger to function in an effective manner.

The comprehension, investigation, and forecasting of the internal flow on the turbocharger's wheels is a crucial challenge that occurs throughout the process of designing and optimizing the performance of the turbocharger's wheels. Computational fluid dynamics (CFD) is one of two methods for assessing new turbocharger wheel designs that are available. The advantages of using computation simulation (CFD) are that it is less expensive, increases speed, and provides more data. A significant portion of the early experimental testing may be rendered unnecessary if an advanced and accurate computer simulation is utilized.

The thermal model of the turbocharger comprises a number of characteristics that cannot be easily obtained by observation of the geometry unless significant simplification is performed. These parameters include five capacitances, four conductances, and seven convective correlations. Although an experimental approach has been built in order to characterize these characteristics for a specific turbocharger, the purpose of this study is to evaluate the predictive capability of the model for a new turbocharger, based on the parameters that have been defined in the past for a device that is quite similar to the one under investigation. Previous research has tested a variety of turbocharger sizes, and basic correlations have been found between exterior geometries and thermal characteristics. These simple correlations have been utilized to compute the parameters of this study, which replicates an industrial scenario.

OBJECTIVE:

1. The investigation of the practical use of turbochargers enables manufacturers to employ engines with a reduced displacement.
2. The improved combustion process will result in the production of a more vigorous and pulsing exhaust gas, which then travels via the exhaust manifold and into the turbine, which is what powers the compressor.

Mettalurgical Properties of Turbocharger

Metals are the subject of metallurgy, which is the study and manipulation of metals and their characteristics. The study of the behavior of metals and the development of methods to enhance their characteristics for use in a variety of contexts is the primary emphasis of this branch of the physical sciences. Metallurgists are employed in a broad variety of sectors, and their primary focus is on working with steel, iron, aluminum, and copper.

The process of extracting metals from their natural sources, such as ores, is an essential component of the discipline. An ore is a naturally occurring rock or mineral that contains a valuable substance, such as a metal or gemstones, and which is capable of being mined and processed for a variety of uses in industry. Ores may be found all over the world.

After extraction has been completed, the ore can be processed to get rid of any impurities that remain and to enhance its overall quality. The process of purifying in metallurgy is analogous to the filtering of water. In the same way that pollutants and impurities are removed from water in order to make it clean and safe to drink, metallurgists utilize a variety of processes in order to remove undesired compounds from metals or ores, therefore making the metals or ores more pure and improving the quality of the metals or ores for the purpose for which they are designed.

Metallurgists are also responsible for researching the microscopic structure of various metals. They investigate the configuration of atoms in metals and how this configuration influences the attributes of metals, such as their strength, hardness, and conductivity. Metallurgists are able to enhance the qualities of metals by altering their structure through procedures such as heating and cooling, which are collectively referred to as "heat treatment."

Metallurgists create new alloys by fusing together several types of metals or by putting in additional components. Imagine that you are combining several colors of paint to produce a masterpiece that is not only more vivid but also more resistant to rust. For instance, stainless steel is an alloy that combines the strength of iron with the corrosion resistance of chromium. Because of this combination, stainless steel is excellent for use in shining kitchen equipment as well as in durable building materials. Imagine getting the very best of both worlds in a single metal mix.

1. **Center Housing** : A bearing system may be found in the center housing (bearing house), which is situated between the compressor and the turbine. This bearing system provides support for the turbine-compressor common shaft. The shaft that has the compressor and turbine wheels attached to it is referred to as the rotating assembly, and this component is referred to as the shaft wheel assembly (SWA). CHRA is an abbreviation for "center housing rotating assembly," which describes the SWA that is mounted in the center housing but does not include the compressor and turbine housings. Gray cast iron is the material that is most often used to cast the central housing, but aluminum is also a viable option in some circumstances. Seals play an important role in preventing oil from getting into the compressor and the turbine. Cooling tubes are an additional option that may be included into the center housing of turbochargers designed for high-temperature exhaust gas applications, such as spark ignition engines.
2. **Bearings.** The design of the turbocharger bearing system is deceptively straightforward, but despite its apparent simplicity, it is vital to the operation of a variety of important processes. The control of radial and axial motion of the shaft and wheels, as well as the minimizing of friction losses in the bearing system, are two of the more significant considerations that must be made. Because of their impact on turbocharger friction and the subsequent influence on engine fuel economy, bearing systems have garnered a significant amount of attention in recent years.
3. The bearings that support the shaft are typically situated in an overhung position between the wheels, with the exception of certain big turbochargers designed for low-speed engines. Because of the flexible rotor design, the turbocharger is guaranteed to work at speeds that are above its first and perhaps second critical speeds. As a result, the turbocharger is able to be subjected to rotor dynamic circumstances such as whirl and synchronous vibration.
4. The seals. Seals can be found on both the front and the back of the bearing housing. These seals constitute a challenging design challenge due to the requirement that frictional losses be kept to a minimum, the relatively considerable movements of the shaft that are caused by bearing clearance, and the unfavorable pressure gradients that can occur under certain situations.

The primary purpose of these seals is to prevent intake air and exhaust gas from entering the central housing of the engine. The pressures in the intake and exhaust systems are generally at a greater level than the pressure that is found in the center housing of the turbocharger, which is often at the same level as the pressure found in the crankcase of the engine. As a result, the primary function of their design would be to ensure that the center housing is hermetically sealed, even under conditions in which the pressure in the center housing is lower than that of the intake and exhaust systems. These seals are not designed to be the major way of stopping oil from leaking out of the center housing and into the exhaust and air systems, as it is not their intended function. Other mechanisms, such as oil deflectors and spinning flingers, are typically utilized in order to prevent oil from coming into contact with these seals.

Supercharging and turbo charging.

The exhaust gases are used to feed the turbocharger, which is a miniature turbo compressor with a radial impeller. It does not contain a combustion chamber. It does this by reclaiming some of the potential and thermal energy contained in the exhaust gases and putting it to use in the compressor section to boost the pressure of the incoming flow to the engine. A supercharger is similar to a turbocharger in that it raises the intake air pressure of an engine; however, it does so by utilizing the power of the crankshaft rather than the power recovered from the exhaust. The fact that the compressor in this scenario might be of the radial type, the lobe type, or the rotary vane type demonstrates the effect that a supercharger has on the normal air Otto and Diesel cycles.

Conventional Turbo charging.

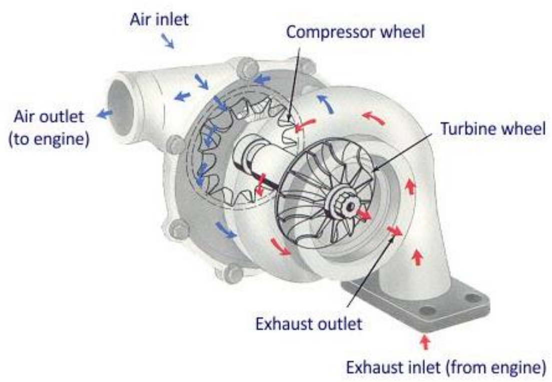

Fig 1 Turbocharger construction and flow of gases

The potential drawback of the turbocharger is that it can only deliver a modest boost pressure while the engine is operating at low speeds. This is because there is a relatively little amount of energy available in the exhaust gases. Figure 10.20 illustrates the level of the boost pressure that is applied to a Ford prototype 1.8-liter DI engine with eight valves. When acceleration is necessary, there is always going to be a delay in boost (also known as turbo lag) because of the inertia of the turbocharger rotor. Watson and Janota give exhaustive documentation of the many aspects of the science of turbo charging.

Turbocharger durability.

Designing turbochargers is often the responsibility of professional vendors. The LCF and HCF in the compressor and turbine wheels of the turbocharger are the primary sources of concern when it comes to concerns of durability in diesel engine system design. The temperatures of the wheel and housing, in addition to the rotational shaft speed, are factors that affect the durability of compressors. The temperature of the air that is discharged from the compressor has a significant influence on both the wheel and the housing temperatures. The alternating strains brought on by the fluctuation in wheel speed that takes place whenever the engine speed or load varies are what produce the LCF of the compressor. The HCF in the turbine is associated with the vibration of the blades, and in some cases, resonance at the inherent frequencies of the blades. Strong shockwave pressure pulses are created at the turbine nozzles or the throat when conditions are such that the inlet pressure of the turbine is extremely high. The gas pulses cause the downstream turbine wheel to get excited, which ultimately results in the wheel failing due to a high critical frequency. When opposed to gasoline engines, diesel engines run with a higher air–fuel ratio, which means that the turbine is subjected to lower exhaust gas temperatures. As a result, the temperature of the exhaust manifold gas is often not a major problem for the durability of the turbine.

When compared to the waste gated turbine, the variable geometry turbine (VGT) has a number of advantages over its predecessor. These advantages include a reduction in engine pumping loss and fuel consumption, flexibility in modulating EGR rate and air–fuel ratio, quicker transient reaction, and improved engine braking. VGT has been gaining popularity for all various sizes of diesel engines (for example, from passenger cars to Class-8 trucks) and for diverse applications (for example, from on-road to off-road such as agriculture and construction equipment and marine engines). Due to the greater number of moving parts needed to regulate the turbine area, variable geometry turbines (VGT) have a tendency to have more durability difficulties than fixed geometry turbines and waste gated turbines in general. The challenges of thermal distortion, interference or seizure, thermo-mechanical fatigue, creep, wear, and corrosion are typically included in the list of concerns about the durability of VGT. The next generation of VGTs should be lighter, less expensive, and have greater thermal durability. This should be the path of future design improvements.

As a result of the turbocharger's potential to boost engine power and fuel efficiency while simultaneously lowering emissions, it has found widespread application in diesel engines. In the last two decades, a greater emphasis from pollution laws has forced car manufacturers to enhance the performance of the engine when it is under part load conditions. As a consequence of this, the utilization of a variable geometry turbine (VGT), which has the ability to improve pressure ratio and modify flow angle under low mass flow conditions by varying the throat area of the nozzle, is a more effective approach of satisfying this need. Nevertheless, powerful excitations near the leading edge of the turbine rotor can be produced even while the engine is decelerating or accelerating in a brief manner. It is possible that this will result in high-cycle fatigue failure (HCF) of the VNT rotor blades.

Leakage and wake from nozzle vanes have a considerable influence on the flow distribution at the inlet of the downstream rotor, the performance of the turbine, and the unsteady load on the rotor blade. When the nozzle vanes are closed to tiny apertures and the turbine is operating at a high pressure ratio, a shock wave will form on the suction side of the nozzle vane at the trailing edge. This shock wave will cause a high pressure response on the surface of the blade by impinging at the leading edge. As a result, the HCF problem of the downstream rotor is contributed to by leakage, in addition to wake and shock wave. Due to the fact that their characteristics are distinct from one another, it is essential to have an in-depth understanding of the process via which each of them produces highly aerodynamic stress on turbine wheels.

In this study, a three-dimensional unsteady numerical simulation of a VNT was carried out in order to explore the effect of nozzle vanes clearance leakage, wake, and shock wave on the rotor blade pressure fluctuations, and then to define where and how these three parameters influence the excitations of the turbine rotor blade. The results of this investigation are presented.

Technical area

The current disclosure relates generally to a compressor wheel for a turbocharger system and in particular to a compressor wheel, which consists of a metal composite with aluminum matrix and / or an aluminum alloy is created, which can include up to five weight percent scandium. The present disclosure also refers to a compressor wheel, which in general consists of a metal composite with aluminum matrix and in specifically for a metal composite with an aluminum matrix.

TURBOCHARGER SYSTEMS

Aluminum alloys are frequently utilized in the production of turbocharger systems. The usage of internal combustion engines is common due to the fact that they are lightweight and simple to pour. In particular, aluminum alloys are becoming increasingly widespread. Used to drive the wheels of the compressor in both single-stage and multi-stage configurations for the formation of turbocharger systems. However, cast aluminum alloys might have restricted fatigue qualities, which in turn unavoidably limit the turbocharger's longevity. As a result, aluminum compressor wheels can occasionally be rather forged than poured in particular circumstances. Despite the fact that the forging is the identical, the outcome is a far more solid and long-lasting compressor wheel. The costs of production are quite expensive.

Because the temperatures of the compressed air can reach between about 200 and 250 degrees Celsius in some applications, the elevated temperatures that result from these conditions may have a negative effect on the compressor wheels at a later time. At these extreme temperatures, aluminum alloys, including cast and wrought alloys, no longer have adequate strength to fulfill the material property criteria for a supercharger wheel that is part of a turbocharger system. This is the case regardless of whether the alloy was wrought or cast. One illustration of such a cast aluminum alloy may be seen in the US publication 2005/0167009, which was contributed by Shoji and others.

Component of turbocharger: The turbocharger is composed of its three most important parts. First, before we go on to the various types of turbochargers, let's have a look at how these components operate.

1. Turbine.
2. Shaft.
3. Compressor.
4. Center housing
5. Intercooler.
6. Waste gate.
7. Blow-off valve.

Turbine : The engine generates exhaust gases at high temperatures and under tremendous pressure, which then goes through the turbine of the turbocharger and pushes the turbine wheel that spun the shaft between the turbine and compressor, which converts heat and pressure into useful kinetic energy. Because a small size can produce additional back pressure and choke the engine, and a large size can cause lag and make it difficult to reach the target from the turbocharger, we need to pick the wheel of the turbine very carefully so that we can maximize the capabilities of the turbocharger.

Turbine blade

A **turbine blade** is a radial aerofoil mounted in the rim of a turbine disc and which produces a tangential force which rotates a turbine rotor. Each turbine disc has many blades. As such they are used in gas turbine engines and steam turbines. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines.To survive in this difficult environment, turbine blades often use exotic materials like superalloys and many different methods of cooling that can be categorized as internal and external cooling, and thermal barrier coatings. Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used. Blades of wind turbines and water turbines are designed to operate in different conditions, which typically involve lower rotational speeds and temperatures.

Shaft The compressor is driven by the rotation that is transmitted from the turbine.

Compressor : The compressor creates a pressure that is distinct from the air that is drawn into the throttle body, intake manifold, and the combustion chamber. This helps to enhance the density of the air, which in turn increases power and ensures that combustion is carried out completely. The increase in pressure created by the turbocharger is the fundamental reason why natural-aspirated engines might benefit from the addition of a turbocharger.

Center housing : In addition to keeping the turbocharger's bearings lubricated and supported, this component is built from a material that is resistant to high temperatures and pressures. **Intercooler** : Heat is generated within the turbocharger system as the pressure inside of it continues to build up. This problem is resolved by the intercooler, which works by cooling the air as it passes through the device on its way to the intake manifold.

Waste gate : It is regulating the movement of the exhaust gas inside the turbocharger system, in state have not regulator that can create an extra amount of boost and damage the component of engine.

TURBOCHARGER WORKING.

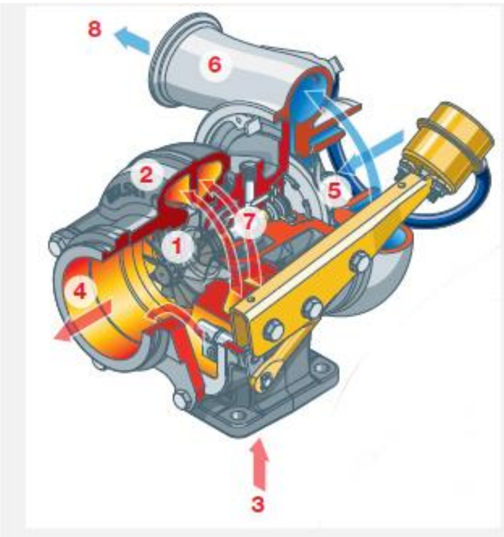

Fig 2.TURBOCHARGER WORKING.

1. The engine has a pipe that directs the exhaust gases to the turbine wheel after they leave the engine.
2. The exhaust forces the turbine wheel forward, causing it to exit the turbine.
3. The turbine wheel drives the compressor wheel at the same speed as it, and then the compressor draws outside air into the system.
4. The air that has been compressed travels, if an intercooler is present, through the manifold to the block engine.

Types of turbocharger: After going over the turbocharger component and how it operates, we will now examine the roles played by the various types of turbochargers.

1. a single turbocharger.
2. Dual turbochargers.
3. A turbo with a twin-scroll design.
5. A turbo with a variable geometry.
6. Variable Twin Scroll Turbo charging System.
7. The Electric Turbo.

1-Single-Turbo

There is no end to the variety that may be achieved using a single turbocharger. When the size of the compressor wheel and the turbine are not the same, the outcome will be torque qualities that are completely different. Smaller turbos have a faster spooling rate, which allows them to produce more low-end oomph than larger turbos. However, larger turbos have a higher top-end capacity. Additionally, journal bearings and ball bearings are found in single turbos. Ball bearings allow the compressor and turbine to spin with less friction, resulting in a quicker spooling speed (however this comes at an additional expense).

Advantages

The engine's power and efficiency may be increased in a cost-effective manner, and the process itself is straightforward in most cases.

- Enables the use of a smaller engine to provide the same level of power as a bigger engine while reducing the overall weight of the system. Contradictions in terms
- Single turbochargers often have an effective RPM range that is on the lower end of the spectrum. Because of this, size becomes a problem, and we will also have to pick between having decent low-end torque and having superior high-end power.
- The turbo reaction could not be as quick as it is with alternative turbo designs.

Twin-Turbo When using two turbochargers instead of a single turbocharger, you have far more customization choices. Each cylinder bank of a V6, V8, or other engine configuration might have a separate turbocharger. Alternately, it is possible to employ a single turbocharger for low RPM and then bypass it to a bigger turbocharger for high RPM (I4, I6, etc.). It is also possible to have two turbos that are almost the same size, with one being utilized at low RPM and the other two being used at higher RPM. Both the BMW X5 M and the BMW X6 M make use of twin-scroll turbochargers, one on either side of the V8. Added Bonuses For parallel twin turbos on 'V' shaped engines are very similar to single turbo setups in advantages and disadvantages.

- It makes it possible to have a torque curve that is significantly flatter and broader when employing sequential turbos or using one turbo at low RPM and both turbos at high RPM. Excellent torque at low RPMs, but the power does not drop down as quickly as it would with a smaller single turbo.

Disadvantages

There is yet another approach, which, as we shall demonstrate in the following section, can accomplish the same effect.both in terms of expense and level of complexity, given that there are roughly twice as many turbo components.

Twin-Scroll

Single-scroll turbochargers are inferior in nearly every respect to their twin-scroll counterparts, which are known for their superior strength. Utilizing two scrolls allows for the exhaust pulses to be segmented. For instance, on four-cylinder engines with a firing sequence of 1-3-4-2, the first and fourth cylinders may feed into the same turbo scroll, but the second and third cylinders could feed into different scrolls. What are the positive aspects of doing so? Let us suppose that the power stroke of cylinder 1 comes to a stop when the piston hits the dead center of the rim, and the exhaust valve starts to open at this point. throughout this time, cylinder 2 completes the exhaust stroke, closes the exhaust valve, and opens the intake valve, despite the fact that there is some overlap throughout this process. Because both exhaust valves are briefly open in a normal single-scroll turbo manifold, the exhaust pressure from cylinder 1 will interfere with cylinder 2's ability to pull in fresh air. This is because both exhaust valves are temporarily open, which reduces the amount of pressure that the turbo hits while also affecting the amount of air that cylinder 2 pulls in. By separating the scrolls into two halves, we may avoid that issue.

CONCLUSION

1. This research is a literature review study that offers a broad overview of how engine testing methodologies might be employed to carry out the required experimental investigation of the turbocharger.
2. To begin, it is abundantly evident that the utilization of "hot gas" technology is a great deal more realistic than any other method since it is able to perfectly reproduce the working circumstances of the turbocharger.
3. Second, because it is simpler to set up a test rig while the exhaust gas is at a low temperature (sometimes known as "cold"), it is usual practice to utilize that gas to spin the turbine.

4. When appropriate downsized engines are used, improved engine outputs and improved fuel efficiency can often be achieved.
5. In addition, the experimental testing methodologies that are provided in this study may be used to conduct an analysis of the various turbocharger designs that are utilized in combination with the downsized engines.
6. After that, the findings can be verified by employing powerful 1D simulation techniques and/or precise 3D CFD simulation instruments.
7. Because of this, choices may be made regarding the kind of turbocharger that is most suited to the kinds of economic developments and energy constraints that will be necessary in the years to come.

REFERENCES

1. 1-6 Ways to Protect Your Turbo Engine. (n.d.). Retrieved from REDEX: https://www.holtsauto.com/redex/news/6-ways-protect-turbo-engine/

2. Avendano, M. (2013, October 22). Getting to Know The Turbocharger - Feature Stories. Retrieved from AutoIndustriya: https://www.autoindustriya.com/features/getting-to-know-theturbocharger.html

3. Bell, C. (2002). Supercharged! Design, Testing and Installation of Supercharger Systems. Bentley Publichers.

4. Chevrolet. (2016, september 22). WHAT IS A TURBOCHARGER AND HOW DOES IT WORK? Retrieved from EAGLE RIDGE: https://www.eagleridgegm.com/what-is-a-turbocharger-andhow-does-it-work/

5. Ganesan, V. (2012). Internal Combustion Engines. India: McGraw Hill Education .

6. Hiereth, H., & Prenninger , P. (2010). Charging the internal combustion engine. Springer.

7. Nguyen-Schäfer, H. (2015). Rotordynamics of Automotive Turbochargers. Ludwigsburg,Germany: springer.

8. Tharad, V. (2018, January 9). Engineering Explained: 6 Different Types Of Turbocharger. Retrieved from linkedin: https://www.linkedin.com/pulse/6-diffrent-types-turbocharger-vijaytharad

9. Turbocharging 101: Some history and basics of turbocharging systems. (2005, April 8). Retrieved from AVIATIONPROS: https://www.aviationpros.com/home/article/10385857/turbocharging-101-some-history-andbasics-of-turbocharging-systems

10. Watson, N., & Janota , M. S. (1982). Turbocharging the Internal Combustion Engine. London: THE MACMILLAN PRESS LTD .

11. Chen T., Zhang Y. and Zhuge W. (2008).Integrated System Simulation for Turbocharged IC Engines. SAE Technical Paper Series, 2008-01-1640

12. Winkler N., Angstrom H. and Olofsson U. (2005).Instantaneous On-Engine Twin-Entry Turbine Efficiency Calculations on a Diesel Engine. SAE Technical Paper Series, 2005-01-3887

13. Stan C. and Taeubert S. (2009). Analysis of engine performances improvement by downsizing in relationship with super- and turbocharging, adapted scavenging and direct injection. SAE Technical Paper Series, 2009-24-0075

14. Chadwell CJ. and Walls M. (2010). Analysis of a SuperTurbocharged Downsized Engine Using 1-D CFD Simulation. SAE Technical Paper Series, 2010-01-1231

15. Petitjean D, Bernardini L., Middlemass C. and Shahed S.M (2004).Advanced gasoline engine turbocharging technology for fuel economy improvements. SAE Technical Paper Series, 2004- 01-0988

16. Hawley J., Wallace F., Cox A., Horrocks R. and Bird G.(1999).Variable geometry turbocharging for lower emissions and improved torque characteristics. Proceedings of the Institution of Mechanical Engineers; 1999; 213, 2; ProQuest Science Journals pg. 145