

FAILURE'S IDENTIFICATION OF TURBOCHARGERS OF INTERNAL COMBUSTION ENGINES BY MEANS OF MULTI-FUNCTIONAL TEST STAND

Marek Idzior, Wojciech Karpiuk, Maciej Bieliński, Tomasz Borowczyk

*Poznan University of Technology
Division of Internal Combustion Engines
Piotrowo Street 3, 60-965 Poznań, Poland
tel.: +48 61 6652119, +48 61 6475993, +48 61 6475962, fax: +48 61 6652204
e-mail: marek.idzior@put.poznan.pl, wojciech.karpiuk@gmail.com
maciej.bielinski@doctorate.put.poznan.pl, tomasz.borowczyk@doctorate.put.poznan.pl*

Abstract

A turbocharger is a relatively simple, but very precisely made component working in conditions, which should be considered hard. Due to hard working conditions, among others: high exhaust temperatures, very high rotational speeds reaching up to 250 000 rpm, precise design and difficult assembly, turbochargers should be considered particularly subject to damage and failure. It is confirmed by data showing an increasing number of failures of such components, which is caused, among others, by the increasing number of vehicles equipped with turbochargers. The considerable cost of a new turbocharger and its relatively easy disassembly coupled with easy access to spare parts in Poland result in establishing of ever more new companies remanufacturing this type of device. The effectiveness of repairs carried out in such plants varies strongly, often being of poor quality due to lack of knowledge, both practical and theoretical, inadequate training of personnel, and many other factors. A common problem, faced by the companies remanufacturing turbochargers, is the lack of tools allowing to reliably checking the selected parameters relevant for subsequent use of remanufactured components. In connection to that in article have been presented identification of common failures occur in turbochargers. Moreover, conception of multi-functional diagnostic test stand have been also presented. Such method will be an extremely useful tool for verifying the effectiveness of repairs, which will be important in terms of their subsequent use (confirmation, that the repair has been performed properly), environmental protection and in case of conflict between the customer and the company (certifying, that the repair has been performed properly). No equipment or other technological solution enabling to achieve aims described above in practice is produced in Poland or abroad.

Keywords: engines, vehicles, transport

1. Introduction

Supercharging the internal combustion engine is delivery of fresh charge of increased density into the cylinder, which enables supplying it with more fuel without altering the air-fuel ratio λ . The aim of the process is to maximize the unit power and efficiency of the engine but also to reduce unitary emission of toxic exhaust components. Turbocharging belongs to the category of compressor supercharging with a flow compressor. The main component is a turbocharger – fluid-flow machine in which the turbine and compressor rotors are mounted on a common shaft (Fig. 1).

2. Failures of cars' turbochargers

Since a turbocharger is lubricated with oil from the engine, it happens that the oil is of insufficient quality. Because of the hard operating conditions in the engine, its physical characteristics (density, viscosity) and other parameters (foaming resistance, for example) deter [1]. Moreover, solid macro particles such as products of abrasive wear of engine's components, corrosive wear etc. can be included in the oil, which microcut, scrape and furrow outer layers of friction nodes. The deterioration of the quality parameters of the oil during the use of the vehicle is a normal phenomenon.

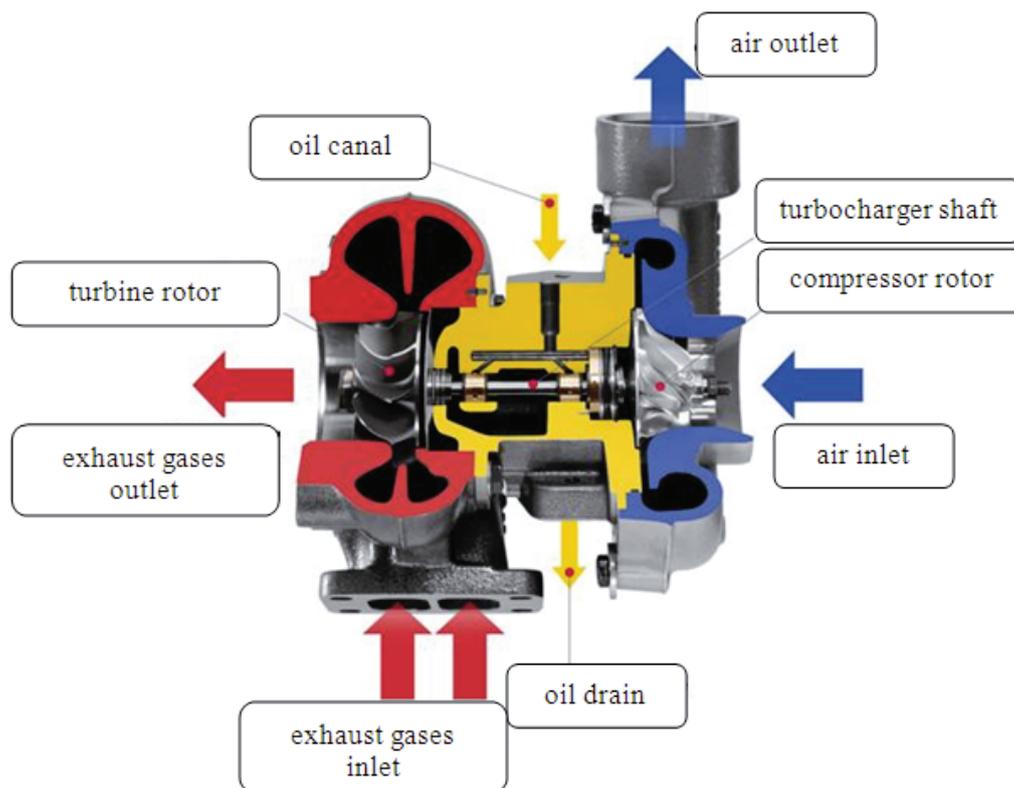


Fig. 1. Cross section and principle of operation of turbochargers

Causes of damage to turbochargers done by oil of poor quality should be sought for in engine oil primarily of poor quality – not complying with the manufacturer’s recommendations. In addition, the oil filter may be inadequate, being of incorrect parameters or choked by soil. The most common cause in this type of failure is however, a result of a lack of periodical or distance-determined oil change according to the manufacturer’s recommendation. Turbocharger damage caused by oil of poor quality results in, among others, deterioration of the operating conditions of the axial and radial bearings, as a result of the diminishing of the diameter of oil holes. It can cause local overheating of the components and growth of the contact temperature, which can result in rapid damage of the turbocharger revealed by, among others, deep scrapes on the rotor’s shaft necks (Fig. 2) and bearing surfaces (Fig. 3), alteration of parameters of the outer contact layers (Fig. 4), decalibration of the holes for bearings in the inner housing or the ring seals becoming stuck in their grooves (Fig. 5).



Fig. 2. View of broken rotor’s shaft necks with deep scrapes



Fig. 3. View of scraped surface of bearing

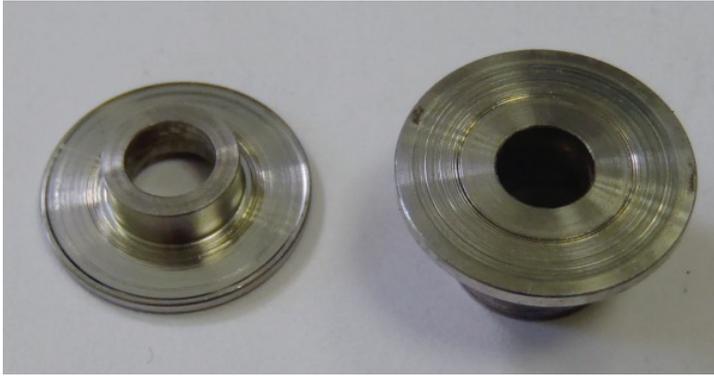


Fig. 4. View of changes in parameters of the outer contact layers



Fig. 5. View of rotor's shaft with ring seals becoming stuck in their grooves

Consequences of improper oil parameters have been described above. Another failure type, also related to oil, is one caused by the change in its operating parameters, for instance pressure drop or a momentary lack of oil. Mechanical parameters are thus of importance – oil should be delivered to the turbocharger in adequate amount and at proper pressure. It is also important that the oil outflows sufficiently quickly out of the friction zone and the inner housing (Fig. 6).

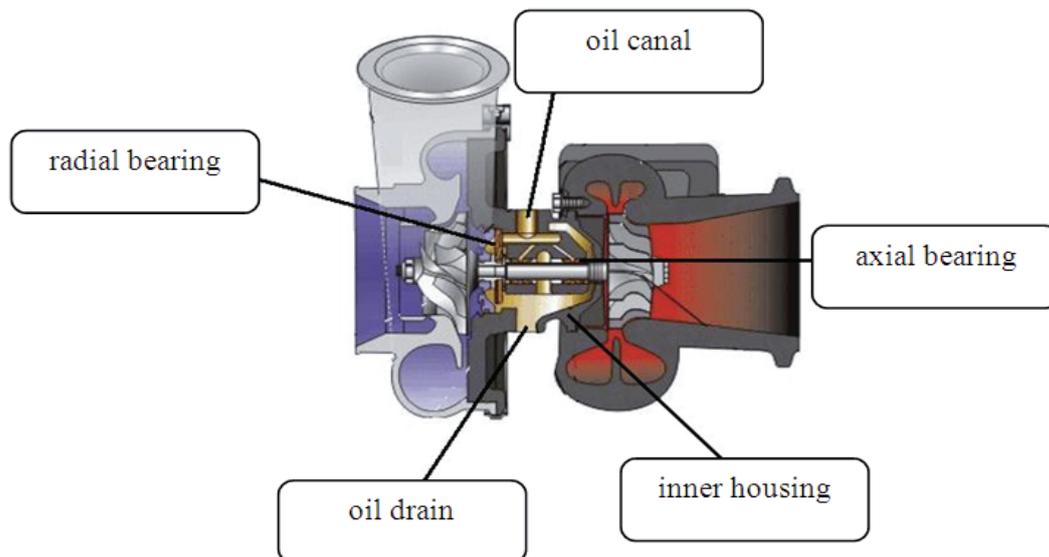


Fig. 6. Cross section of turbocharger with visible inner housing and oil canal

If the oil pressure is improper and if there is too little of it, no oil film can be created. Contact temperature also increases rapidly, and in connection with high rotation velocities (around 200 000 rpm) emitted friction heat reaches high values [2]. Causes of momentary interruptions in oil delivery to the turbocharger can be a result of improper use, for instance – long inter-operational periods, failing to service the vehicle at given frequency or prolonged operating of the engine under high load at low rotational speeds. Another cause of the lack of lubrication and cooling of the friction nodes is a choked or out of order lubrication system of the engine hindering the oil flow in and out of the turbocharger. Damage to the turbocharger caused by interruptions in oil delivery is revealed by:

- damage of the outer layers of bearings and rotors' shaft neck (Fig. 7),
- alteration of physical properties of the material the shaft and bearings are made of (Fig. 8),
- the bearing sleeves becoming stuck in the inner housing holes (Fig. 9),
- thermolysis of the oil components (coking) – leading to carbon depositing in oil holes of the inner housing, causing them to choke (Fig. 10).



Fig. 7. View of damaged bearing

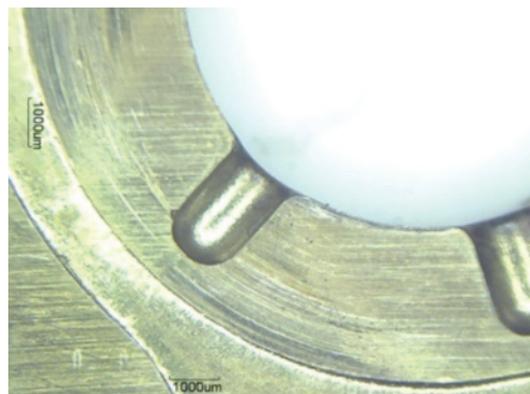


Fig. 8. View of alteration of bearing material



Fig. 9. View of faded bearing (dry friction)



Fig. 10. View of turbine rotor with carbon depositing

Another type of failure identified is that caused by overheating. It has in principle two causes: too high exhaust temperature and sudden stoppage of the engine preceded by driving with considerable load and rotational speed [3]. Hot exhaust strongly heats the turbocharger's components – particularly cast iron housing of the turbine and the inner housing (Fig. 11).



Fig. 11. View of bearing with hot tracks

Excessive exhaust temperature may result from improper operation of the fuel injection system related to improper operation of the fuel injectors, worn out nozzles or out of order injection control unit. Another cause is improper operation of engine control unit, or exhaust system – hindered outflow of exhaust as a result of a choked diesel particulate filter. As has been observed, sudden stoppage of a engine with a heated and run up turbocharger (rotor temperature $\approx 600^{\circ}\text{C}$, rotational speed $\approx 200\,000$ rpm) also leads to undesirable overheating. After engine stoppage no more exhaust flows to the turbine wheel, simultaneously the pressure and amount of oil flowing into and

out of the turbocharger rapidly drops. Oil heats up very quickly as a result of heat conduction and reaches its coking temperature in a very short time. It settles as flow hindering carbon deposit in oil passages. The turbochargers rotor does not stop at once – it turns multiple times before it comes to a stop. The oil in bearings does not provide for a sufficient oil film, contacts become overheated and outer layers attenuated. Thermal stresses also built in the shaft, contributing to its losing axial symmetry, which entails unbalance.

The last common type of failure is that caused by foreign matter. This type of failure is a result of foreign matter working its way to the in- or outflow system (Fig. 12).

The failure is of an erosion type and depends on the size of the body reaching the rotors blades. Even the smallest body carried with the exhaust or air flow reaching the rotor strongly impacts the blades as a result of the high energy of the gas flow (Fig. 13).



Fig. 12. View of exhaust steering wheel with contaminations on surface



Fig. 13. View of compression rotor with tracks caused by small body

Foreign matter reaching the compressor or turbine wheels originate in the inflow system section – from the untight inflow system, soiled and worn out air filter or foreign matter being left in the inflow channel during assembly or repair. In the outflow system section, it is usually the engine parts: parts of valves, valve-seats, guides, rings, heater plugs, injectors, but also solid parts of carbon deposit or rust.

3. Conception of multifunctional stand for car turbochargers diagnostic

On the basis of identification of described failures a conception of device which allows for turbochargers diagnostics have been elaborated. For the research of wear and destruction processes of turbochargers, and so their diagnostics, a test stand is needed which will enable to simulate the component's operating conditions, i.e. accelerating the turbocharger's rotor to a given speed, ensuring constant lubricant parameters and setting the desired parameters of the charging air. The companies specializing in design and examination of the manufactured turbochargers use devices enabling them to create flow characteristics of the turbine and compressor and which can be also adapted for research of destructive processes. Such devices use either compressed air from a tank, or hot combustion gases from an exhaust generator as power feed. The basic disadvantage of such solutions is the big volume of the air tank, being a result of a difference in energy states of air and exhaust. The exhaust, which in real conditions propels the turbocharger's rotor, has considerable energy, which derives mostly from its speed (around 500 m/s) and temperature (up to 1000°C). Moreover, the exhaust stream generated by the engine amounts to 0.1-50 m³/min, depending on the engine size and rotational speed. In practice such solutions are often abandoned and the rotor is driven by exhaust in the so-called hot gas test [4] (Fig. 14).

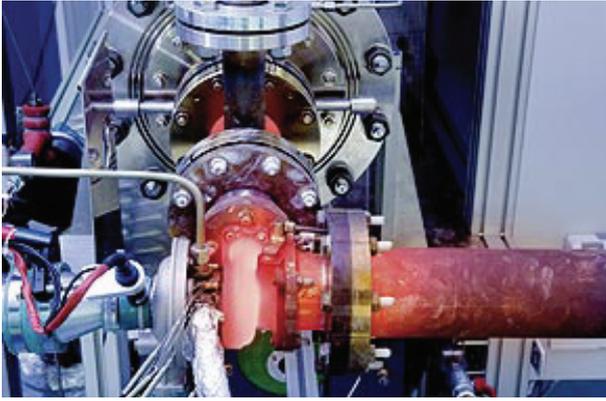


Fig. 14. View of devices which allows for turbochargers testing

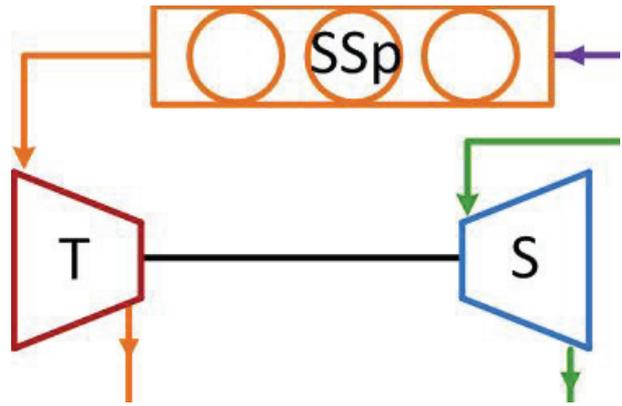


Fig. 15. Schematic diagram of turbochargers test stand

The devices used for this procedure are fitted with an exhaust generator of adjustable parameters: rate of delivery, temperature and pressure. Similarly as with the air tank solution, also this device enables to determine the turbocharger's characteristics. It is also possible to test the turbine under extremely hard conditions and conduct fatigue research as well as continuous monitoring of the operating conditions.

Based on the presented information, in the first phase a solution has been chosen, in which the turbocharger shall be propelled by an exhaust stream (Fig. 15). The research version of the stand uses a normally aspirated combustion engine being the exhaust generator. Spark-ignition engine coupled with a water brake, which receives the power, has been used for the purpose – such a device is in possession of engine test house of the Combustion Engines Laboratory of the Poznań University of Technology (Fig. 16).

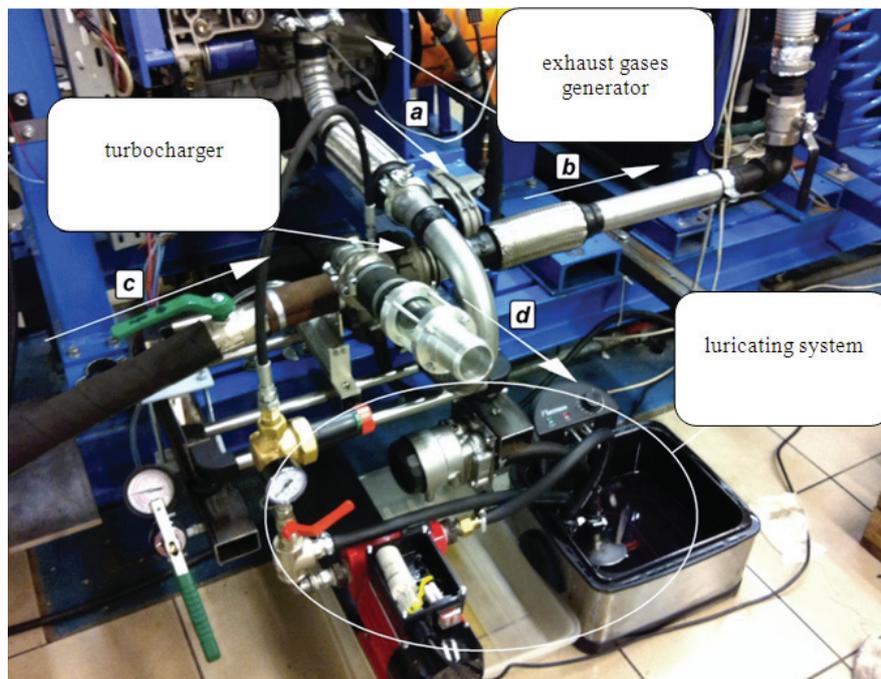


Fig. 16. View of turbochargers test stand

The engine is fitted with a complete apparatus for constant operation and power and torque adjustment, thanks to which it is possible to generate a controlled exhaust stream of a given parameter, i.e. temperature or pressure. Air and fuel are delivered to the engine's combustion chamber, where the combustion of the air-fuel mixture takes place.

After that, gasses reaching the turbine blades propel the turbocharger. As distinguished from the engine propelling a vehicle, the compressed air is not used in any way and the system is not coupled with the engine's inflow system. The main advantage of the described stand is the fact, that research conditions are really close to real ones. The enthalpy of the exhaust and pressure fluctuations are almost identical to those in the exhaust manifold of a turbocharged combustion engine. The compressed air, which reaches the temperatures of 130°C, flows to the heat exchanger, where it is cooled by tens of degrees, and then flows to the dampening system and finally the exhaust system. The turbocharger's shaft with radial and axial slide bearings is lubricated with engine oil from an independent lubrication system. Gear oil pump is driven by an electric motor controlled with an inverter. Such concept enables to simulate variable rate of delivery of the oil pump as a function of a rotational speed of a real combustion engine. The lubrication system is fitted with an independent tank enabling the maintenance of a given temperature, and with an oil filter. Sensors and data-collecting apparatus are used in each of the segments of the system for control and data collection.

During the development of the stand and collecting knowledge referring to the phenomena behind the wear processes of turbochargers, vibrations of the turbocharger's rotor proved to be a significant parameter. Radial microdislocations of the shaft rotating at high speeds during the operating of the component generate vibrations, which can be registered with an especially prepared system. Thus a necessity to measure the vibration during operating has arisen. Data collection is realized thanks to use of accelerometric sensors fixed to the handles fastening the turbocharger. Such a system enables to research the system's vibrations during operating and in transitional states.

4. Conclusions

Presented stand for turbochargers testing with the use of combustion engines as exhaust generator, with external lubricating and cooling systems allows for carried out tests, diagnostics, as well as checking of effectiveness of functioning main elements of turbocharging system. Main advantages of described solution is lack possibilities of car engine damage, which is connected by gas tube and has common lubricating system. All inefficiencies of engine damage may affect on turbocharger system initiating other damages. External power system provides safety and fully latitude of parameters during tests. It allows also for simulations of conditions which are very similar to real conditions.

References

- [1] Delvigne, T., *Oil Consumption Sources in a Modern Gasoline Engine Including Contribution of Blow-by Separator and Turbocharger: An Experimental Study Based on the Use of Radio-tracers*, SAE Technical Paper, 2010-01-2256.
- [2] Manni, M., Carriero, M., Roselli, A., *A Study of Oil Consumption on a Diesel Engine with Independently Lubricated Turbocharger*, SAE Technical Paper, 2002-01-2730.
- [3] Noguchi, T., Takata, Y., Yamashita, Y., *220,000-r/min, 2-kW PM Motor Drive for Turbocharger*, Electrical Engineering in Japan, Vol. 161, No. 3, 2007.
- [4] *Turbocharger Test Stand with a Hot Gas Generator for High-Performance Supercharging Systems*, MTZ, Vol. 69, 2008.

