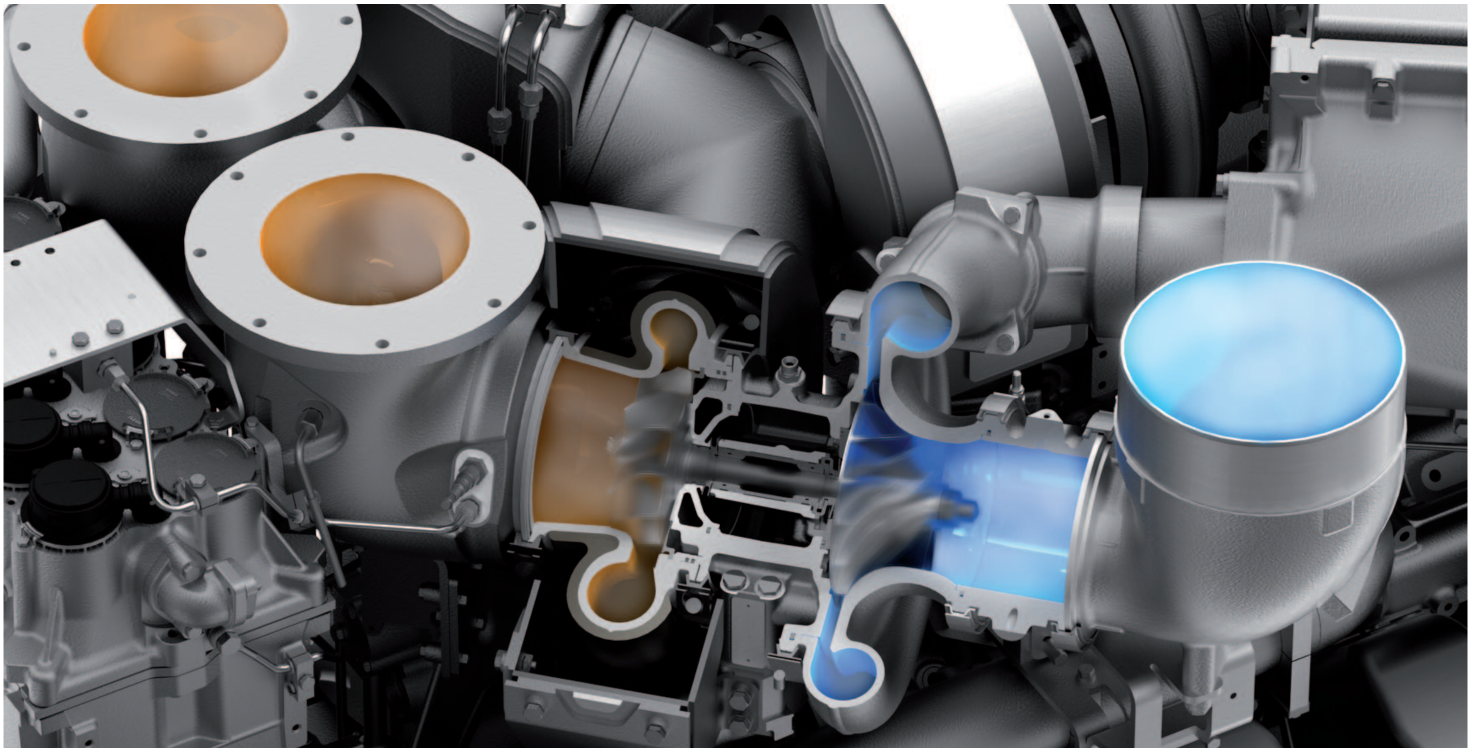
Engine technology

Turbocharging: Key technology for high-performance engines



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The performance of an internal combustion engine can be increased by adding turbocharging. 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. MTU develops this key technology for high-performance engines in-house.

Turbocharger development and production at MTU

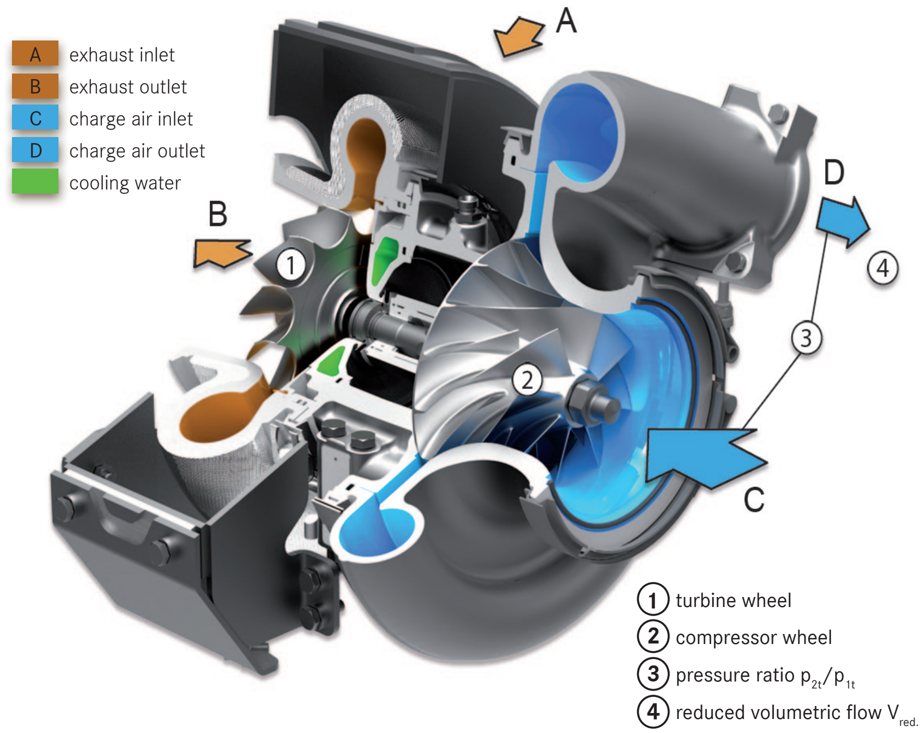
Turbocharging is an integral component of the engine design concept. It shapes the characteristics of the engine more than almost any other system, as it affects its economy, dynamics and emission characteristics. This is why turbocharging is one of MTU's key technologies. MTU has a tradition of maintaining the expertise for developing and producing its turbochargers in-house. The range of MTU turbochargers extends across engine power ratings from 400 to 10,000 kW. Turbochargers are purchased for engine designs in which synergy effects with the commercial vehicles sector can be used.

The global market for turbochargers is dominated by car and commercial vehicle applications. By comparison, the number of turbochargers fitted to industrial engines is negligible. The result is that turbocharger manufacturers rarely produce specialized designs for industrial engine manufactures. Where customers' requirements of the engines are such that they cannot be satisfied by purchased turbochargers, MTU develops and produces the turbochargers itself.

Taking all engine series into account, MTU produces roughly 50 percent of the turbochargers in-house. The present range of MTU turbochargers encompasses five series – the ZRT 12, ZRT 13, ZRT 35, ZRT 36 and ZRT 57 (see Figure 1), and is based on a concept of using as many common parts as possible. In the case of the new Series 4000 engine for rail applications with regulated two-stage turbocharging, for instance, all three turbochargers in the system are identical. This simplifies the logistics in production and the supply of spare parts to customers.

Due to its in-house development and production of turbochargers, MTU is in a position to meet customer demands for highly responsive and powerful engines. MTU 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 the MTU turbochargers are configured specifically to meet the engine specifications, they are easily integrated into the overall engine package. This makes the engines very compact – a decisive advantage in applications where installation space is at a premium.

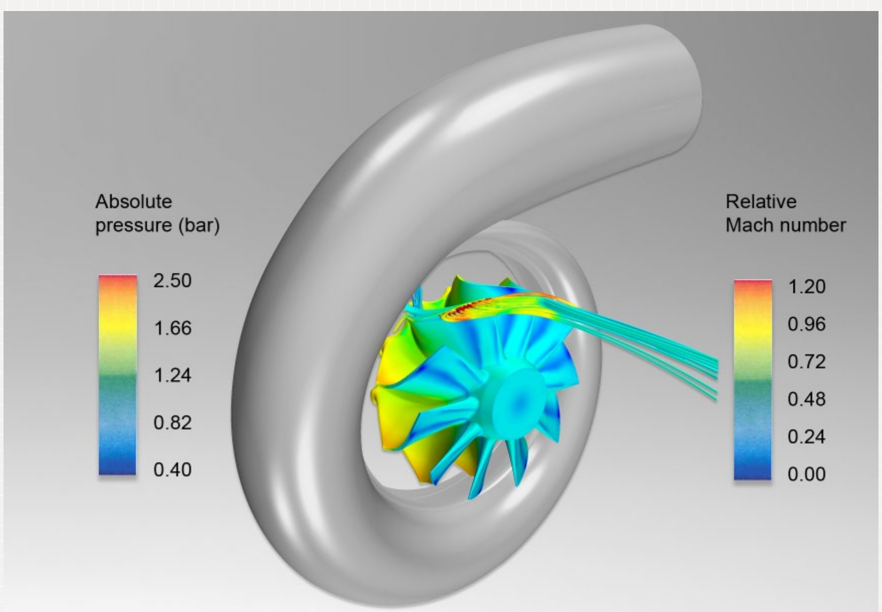
Fig. 1: **Current MTU turbocharger program (ZRT 12, 13, 35, 36, 57)**
MTU's current turbocharger family includes five series and is based on a concept of using as many common parts as possible.



	small size series **ZRT 12, ZRT 13**	medium size series **ZRT 35, ZRT 36**	large size series **ZRT 57**
1	Ø 103-123 mm	Ø 158-185 mm	Ø 245 mm
2	Ø 115-135 mm	Ø 179-210 mm	Ø 265-270 mm
3	up to 5.2	up to 5.4	up to 5.4
4	0.2-0.9 m^3/s	0.8-2.0 m^3/s	1.8-3.5 m^3/s

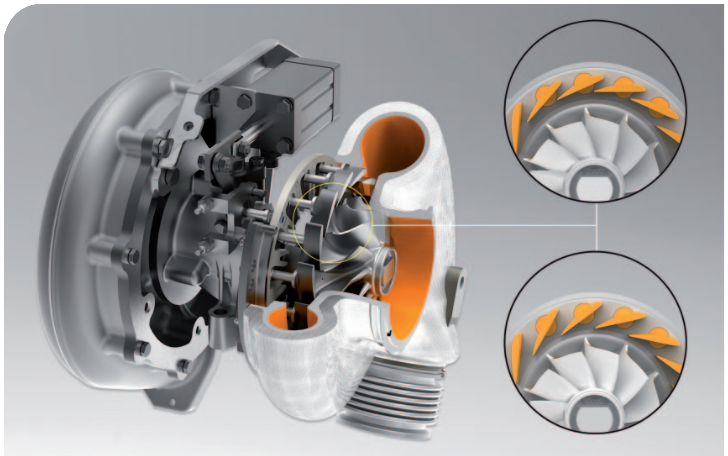
In recent years, the operating conditions of some applications have become tougher. The power units are subjected to a high number of load cycles, which also has an effect on the service life of the turbochargers. MTU has taken these changes into account in the development of its turbochargers, has further optimized the time between overhauls (TBO) and brought this in line with the engines. In the case of the Series 4000 rail engine, for example, turbocharger TBO is as high as 15,000 hours depending on the number of load cycles per hour. This means short maintenance periods and costs – this also applies to the turbochargers. In the turbocharger development processes, MTU makes use of the possibilities offered by efficient calculation and simulation tools.

Fig. 2: **Use of three-dimensional computation procedures for simulating the airflow and the mechanical structural loads to optimize turbocharger performance**
The turbochargers must retain the required characteristics throughout their entire service lives. To this end, MTU works with three-dimensional computation procedures to simulate the airflow and the mechanical structural loads.



When a new turbocharger is produced, it has already gone through a whole sequence of analytical optimization processes in thermodynamics, structural mechanics, durability and containment strength, for example, by the time it is put on the test bench. Analysis fundamentally involves optimization of the component by the use of three-dimensional computation procedures for simulating the airflow and the mechanical structural loads (see Figure 2). In this way, MTU ensures that the turbochargers have the required characteristics when they finally go into service and retain them throughout their entire service lives.

Turbochargers are subjected to high thermal



Turbocharger with variable turbine geometry (VTG)

With variable turbine geometry, the power delivery and response characteristics of the turbocharger can be better adapted to the dynamic engine operating conditions. The exhaust passes over adjustable guides to the turbine blades so that the turbine spools up quickly at low engine speeds and subsequently allows high exhaust gas flow rates.

loads in operation. Accordingly, seals and bearings are thermally isolated and, if necessary, water-cooled. To limit the surface temperature, MTU uses a water-cooled impeller blade on highly turbocharged engines, which simultaneously relieves some of the load on the intercooler. In marine applications, the turbine is cradled in a water-cooled connecting block (see Figure 3). The turbochargers thus also satisfy the SOLAS Directive (Safety of Life at Sea) for marine applications, which stipulates that, for safety reasons, the surface temperature may not exceed 220 degrees Celsius.

Implementation of turbocharging at MTU
As a matter of principle, MTU equips all engines from the various engines series with turbochargers. Within a design series, the turbocharging is matched to the specific equirements of the particular application. This means that a power generation engine, which always runs at the same speed, needs a different turbocharger setup than a vehicle engine. A vehicle engine is driven dynamically – it has to deliver high performance from idling speed right through to maximum revs – and the turbocharger characteristics have to be matched to the broad power band. The challenge is that a turbocharger can be set up either for a wide speed range or a high boost pressure. For engines earmarked for dynamic applications, therefore, MTU has designed the turbochargers to deliver sufficient boost pressure while covering as broad a range of engine speeds as possible.

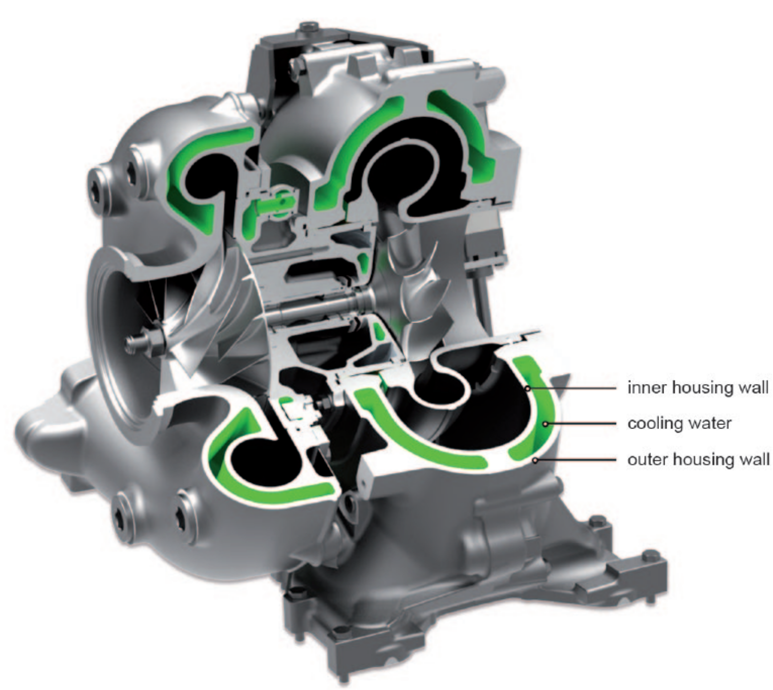


Fig. 3: **High-performance turbocharger with water-cooled casing and compressor impeller**
Using water cooling for the casing and compressor impeller ensures that the engine's surface temperature is limited, which makes MTU turbochargers thermally very durable.

For applications that demand even more dynamic power response, particularly in marine applications, MTU uses the sequential turbocharging principle. It involves multiple turbochargers being sequentially linked. One turbocharger produces the boost pressure for low engines speeds, and when the engine is revving faster or when more power needs to be developed, additional turbochargers are added so that sufficient air is delivered to the cylinders.

To provide highly responsive engine dynamics, the Series 890 engines, which are designed for high performance in military vehicles, have variable turbine geometry. With this technology, the exhaust passes over adjustable wings to the turbine blades so that the turbine spools up quickly at low engine speeds and subsequently allows high exhaust gas flow rates. For the new engine generations to achieve high performance, MTU uses two-stage turbocharging. In the early 1980s, MTU already equipped the Series 1163 with completely integrated two-stage turbocharging with intercooling. Up to five sequentially arranged turbocharger groups consisting of high and low-pressure stages enable the engine to deliver 7,400 kW of power.

New demands on turbocharging due to new emissions legislation
Today, the ongoing development of engines is definitively determined by the continual tightening of emissions standards. This means that additional systems that prevent the production of diesel particulates or nitrogen oxides during the combustion process or clean them further downstream such as the Miller process, exhaust gas recirculation (EGR), selective catalytic reduction (SCR) or a diesel particulate filter (DPF) have to be integrated into the overall engine design concept. For MTU, turbocharging is one of the key technologies in these low-emission concepts. This is because it is only with a compatible turbocharging system that the tendency of these additional systems to negatively affect

engine performance and responsiveness can be prevented. A common feature of all emissions-reducing technologies is that they diminish the effect of the turbocharging. The Miller process, exhaust gas recirculation and diesel particulate filter create higher exhaust backpressure; exhaust gas recirculation increases the air mass that has to be delivered to the cylinder. To put it simply, the turbocharger has to compress the air at a higher rate, i.e. it must force more air into the combustion chamber to provide the same amount of oxygen for combustion as before.

As research by MTU has shown, the single-stage turbocharging previously used will no longer be sufficient for most applications in the future. For engines designed to comply with tough emissions standards, the specialist for propulsion solutions will opt for regulated two-stage turbocharging (Figure 4). This is a system that ensures a constantly high rate of intake air delivery to the engine at all operating points and even under extreme ambient conditions (intake air temperature, altitude, backpressure). It involves pre-compression of the intake air by low-pressure turbochargers followed by further compression in high-pressure turbochargers. Control of the turbocharger system is integrated into MTU's electronic engine management system ECU (Engine Control Unit), which was developed in-house.

The innovative regulated two-stage turbocharging system is being used for the first time for the new Series 4000 engine for rail applications. It meets EU Directive 97/68/EC Stage IIIB emission requirements that have been in place for diesel locomotives in Europe since 2012. In the current engine series for other mobile applications such as construction and industry, regulated two-stage turbocharging is implemented respectively definitely planned. For stationary applications such as power generation, in which the demands on turbocharger dynamic response are not so high, the more economical single-stage turbocharging will continue to be used.

Intercooling

When the air is compressed by the turbocharger, it heats up. Intercooling further increases the air density so that greater air mass and thus more oxygen enters the cylinder. The regulated two-stage turbocharging system works with two intercoolers. The first is located between the low-pressure and the high-pressure stage, and the second downstream of the high-pressure stage. Intercooling provides more efficient compression in the following high-pressure stage, which leads to a higher efficiency level of the turbocharging system. In the case of all MTU engines, the intercoolers are highly integrated into the engine unit and have a very small space requirement.

Summary

Turbocharging helps MTU engines to achieve low fuel consumption and high performance across a broad range of operating speeds. In addition to MTU's other key technologies, it is a major component of the strategies to comply with the increasingly tougher emission restrictions to come without sacrificing engine performance or efficiency. The company has a tradition of developing and producing its own turbochargers for high-performance applications in-house. They are configured specifically to satisfy the high demands of the engines in terms of economy, performance, dynamic response and service life. Because of the high level of integration of the MTU turbochargers in the engine package, customers benefit

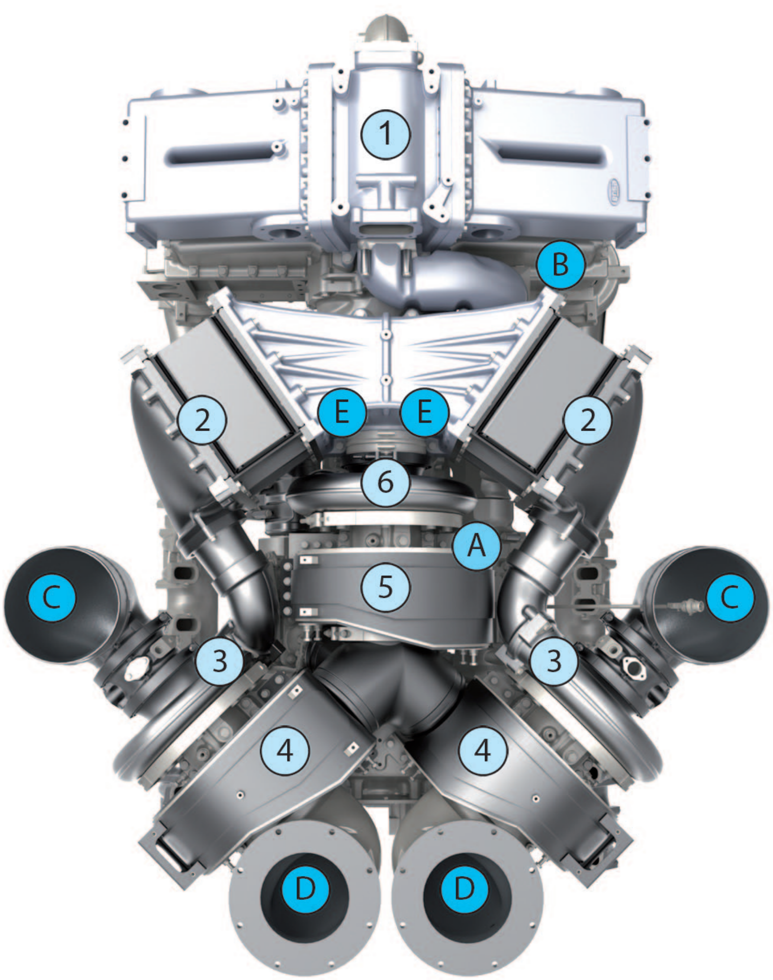


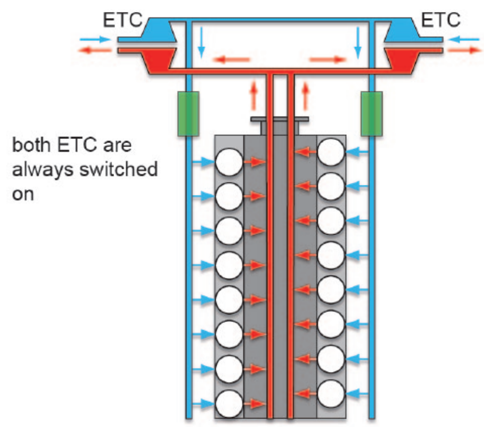
Fig. 4: **Regulated two-stage turbocharging to meet current and future emission standards**
Since single-stage turbocharging will no longer be sufficient to comply with the increasingly tougher current and future emission standards, MTU opts for a regulated two-stage turbocharging in most current engine series.

1. charge air cooler
2. intercooler
3. low-pressure compressor
4. low-pressure turbine
5. high-pressure turbine
6. high-pressure compressor

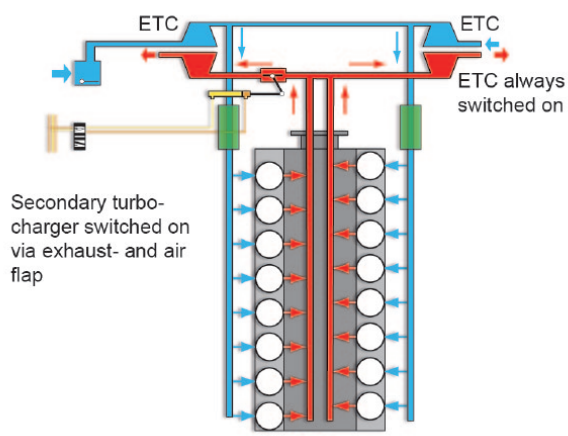
- A from high-pressure compressor to charge air cooler
- B from charge air cooler to cylinder bank
- C intake air
- D exhaust outlet
- E from intercooler to high-pressure compressor

Glossary

Single-stage turbocharging
In the case of single-stage turbocharging, the boost pressure for the entire range of engine speeds and loads is generated by a single turbocharger.

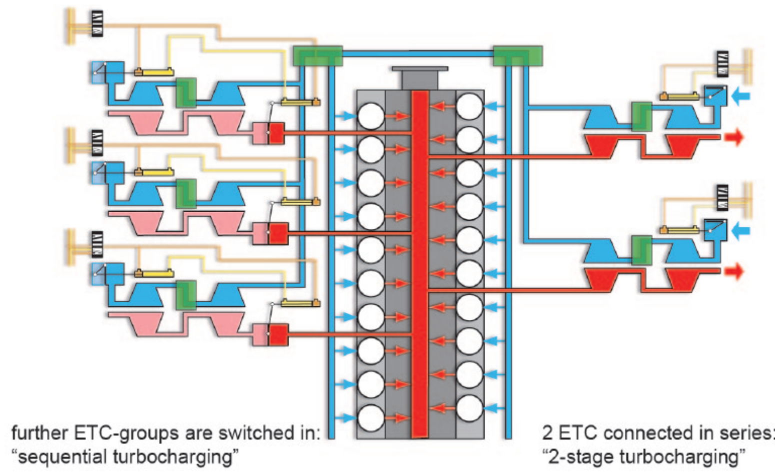


Sequential single-stage turbocharging
In the case of sequential single-stage turbocharging, individual turbochargers are added sequentially in parallel depending on the engine speed and load by means of valves in the intake and exhaust systems.

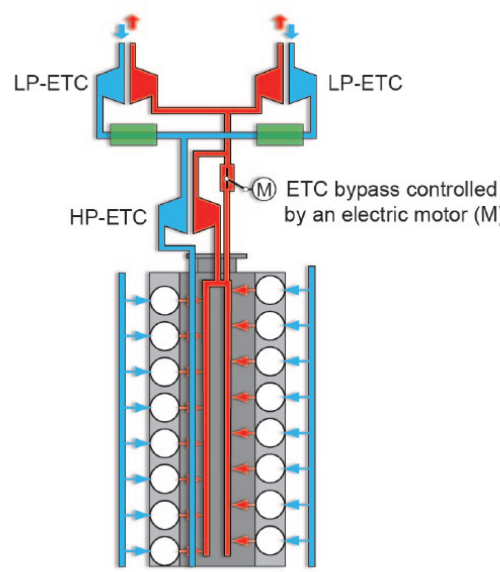


Glossary

Sequential two-stage turbocharging
Basically speaking, sequential two-stage turbocharging operates in the same way as sequential single-stage turbocharging. However, instead of an individual turbocharger in each case, a pair of turbochargers is added or disconnected as required.



Regulated two-stage turbocharging
In the case of regulated two-stage turbocharging, two turbochargers are connected in series. In the system configuration employed by MTU, the exhaust flow from the cylinders is split so that part of it passes through the high-pressure (HP) turbine and the rest is diverted through a bypass by a controllable wastegate valve. The entire mass flow then flows through the low-pressure turbine (LP).



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MTU is a brand of Rolls-Royce Power Systems AG. MTU high-speed engines and propulsion systems provide power for marine, rail, power generation, oil and gas, agriculture, mining, construction and industrial, and defense applications. The portfolio is comprised of diesel engines with up to 10,000 kilowatts (kW) power output, gas engines up to 2,150 kW and gas turbines up to 35,320 kW. MTU also offers customized electronic monitoring and control systems for its engines and propulsion systems.

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