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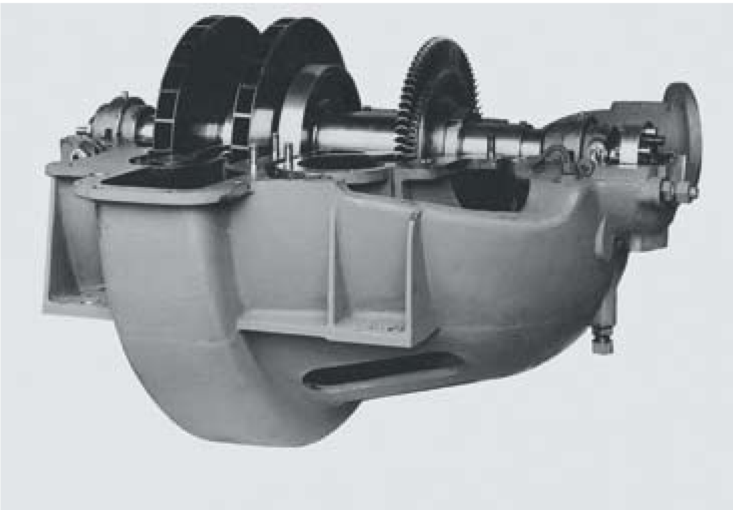
Turbocharging in Switzerland - A history

Pioneering era

Diesel sets the scene

The story of the exhaust gas turbocharger began in a period of phenomenal technical progress. The early years of the twentieth century were remarkable for the breakthroughs they produced. Engineers and entrepreneurs alike were active in the promising field of thermal machines. Rudolf Diesel had patented the engine named after him already in 1892, and its efficiency was by now better than 30 percent. (Diesel even mentioned supercharging in an early patent claim, but later experiments did not produce the high efficiency he was seeking, so he decided to take it no further).

The first diesel engines of MAN (Maschinenfabrik Augsburg-Nürnberg) in Germany and B&W (Burmeister & Wain) in Denmark, date from this period. And in Baden, less than 50 kilometers away, a certain electrical engineering company by the name of Brown, Boveri & Cie was celebrating its first decade in business by embarking on an exciting new venture. It was the construction of continental Europe's first steam turbine, the very branch of engineering that would later bring forth the BBC exhaust gas turbocharger.



World's first turbocharger for a large diesel engine. Delivered in 1924, it had external plain bearings and a two-stage compressor for a pressure ratio of 1.35.

Innovative ideas prevail when their time comes, the right partners are involved and conditions are right.

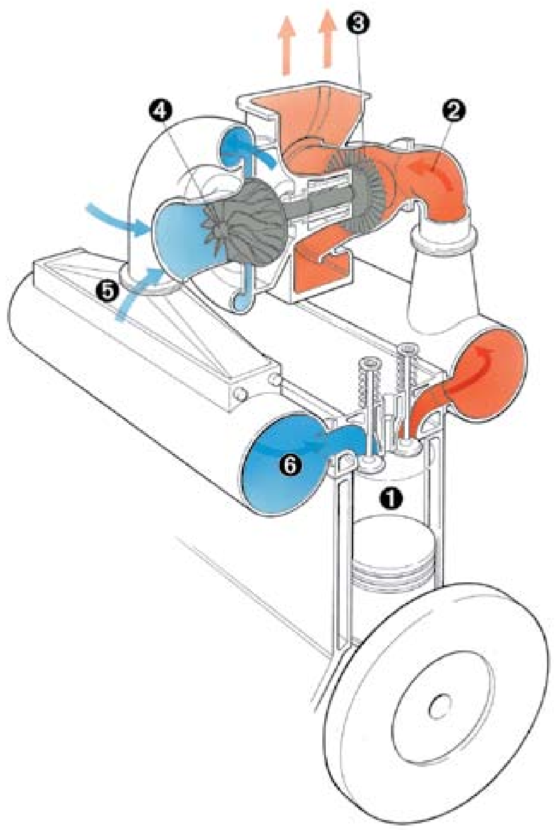
The man we have to thank for the exhaust gas turbocharger is Swiss engineer and inventor Alfred Buechi, who filed his application to patent a "highly supercharged compound engine" in

1905.

His ingenious idea was to use the exhaust gases of a diesel engine to drive a compressor via a turbine and force compressed air into the cylinders, thereby increasing the power output of the engine. Previously useless waste energy was thus to be transformed into additional power.

Later came his patent for a multi-stage turbine for circulating liquids and gases, and in 1915 his important “scavenging” patent. Brown Boveri (BBC), one of the founding companies of ABB, recognized the tremendous potential of exhaust gas turbocharging and entered into a partnership for its development and application. BBC brought financial resources to the enterprise as well as expertise and experience in turbine and compressor construction.

The first turbocharger for a large diesel engine was delivered in 1924. This marked the beginning of a phase of intensive research and development at BBC. The engineers in Baden, Switzerland, began to devise new and improved turbochargers of strikingly greater efficiency. It was the beginning of a success story that continues to this day.



How turbocharging works

The output of an internal combustion engine is determined by the amount of air and fuel that can be pressed into its cylinders (1) and by the engine’s speed. Turbochargers supply air to the engine at a high pressure, so more air is forced into the cylinders and is available for combustion. An exhaust gas turbocharger is driven, as its name suggests, by the engine’s exhaust gas (2). This gas, at a temperature approaching 600°C, is directed at high velocity onto the blades of a turbine (3), which drives a compressor wheel (4) mounted on the same shaft. As it rotates, the wheel (or “impeller”), sucks in ambient air through a filter silencer, compresses it and feeds it via an after-cooler (5) to the engine’s air receiver (6), from where it passes to the cylinders. Turbocharging increases engine out-put by up to four times. Thus, 75% of engine power is dependent upon the turbocharger.

Turbocharging's potential is recognized

The change in Brown Boveri's policy came in 1923 with the publication in Germany of a report on low-pressure supercharging trials carried out by MAN. These trials, on a 160-rpm, four-stroke engine, had shown that with a charge pressure of just 1.35 bar the engine output increased by 33% even after the power for the electrically driven blower had been subtracted. The use of exhaust gas to drive the compressor promised a further 6–8% increase in power as well as lower fuel consumption. On top of this, the operating pressure, the combustion temperatures and the heat load on the walls all remained within acceptable limits.
Brown Boveri now decided to apply the know-how it had acquired building turbines and compressors to the development of superchargers.

First standardized turbochargers

In 1932 an important design decision was made. Now that an optimal technical solution had been found, Brown Boveri's design engineers went on to formulate specifications for a standardized range of turbochargers. This offered nine sizes, corresponding to compressor diameters ranging from 110 to 750 mm. Horizontal-axis units were denoted VTx and the vertical-axis machines VTy. Many of their features, such as (self-lubricated) external ball bearings, water cooling and the wide use of standard parts, were designed to make service work easier, but the decision to make the turbochargers modular was key as it meant that they could be fitted to an enormous range of engines.

The two-stroke engine challenge

The leap in diesel engine efficiency that had taken place in the 1920s was made possible by direct fuel injection and turbocharging. In the meantime, largely thanks to turbocharging, the four-stroke engines had strengthened their position relative to the two-stroke machines. But two-stroke engine development had not stood still, either. MAN and Sulzer, for example, obtained interesting results with experimental two-stroke engines in the early 1930s. However, neither of these engines could really compete with the four-stroke machines.

Developments in two-stroke turbocharging

Brown Boveri had already signalled its interest in two-stroke turbocharging in 1925 with its purchase of the "Curtis" patent. This covered the so-called series arrangement, in which the turbocharger feeds air into the mechanical scavenging air blower of the two-stroke engine, thus guaranteeing start and operation at low load. As the engine output increases, the blower load is automatically reduced.

An internal study by Brown Boveri in 1934 also dealt with the supercharging of a 5,000 horsepower Sulzer two-stroke engine. It showed that by using a turbocharger with aftercooler and pulse operation, under full load the turbocharger alone could be expected to supply enough air. Partial-load solutions, such as auxiliary blowers and supplementary drives, were also mentioned in the study.

Later, in 1940, tests were carried out with a prototype VTx750 with radial-flow wheel on a 7,500 horsepower two-stroke Sulzer engine. The results, however, were disappointing, and further tests were halted.

Thus, until after World War II, turbocharging with exhaust-driven turbochargers was confined exclusively to four-stroke engines. The two-stroke engine, with its low exhaust-gas temperatures and dependence on a blower for the gas exchange, presented significant difficulties due to the low turbine and compressor efficiency at the time. Not until compressors and turbines with higher efficiencies were developed did turbocharging two-stroke marine engines become a practical proposition. Thereafter, the use of exhaust gas turbocharging increased rapidly, helping the two-stroke engine to achieve absolute supremacy as a direct drive, slow-running marine engine.

TURBOCHARGING'S TRIUMPHANT MARCH

The VTR..0 is launched

From 1940 on, Brown Boveri had a new range of turbochargers under development. Denoted VTR, these had an open radial-flow compressor (hence the R) and light rotor, flexibly mounted external roller bearings and a self-lubricating system. Component standardization allowed large-scale production, and therefore competitive pricing. The introduction of the VTR..0 series after World War II was a significant milestone in the BBC turbocharger story. With a compressor efficiency of 75% for a pressure ratio of 2, it was only the start of what was to come, but the BBC VTR..0 turbocharger marked the beginning of a new era.

It was now possible to turbocharge two-stroke engines with engine-driven scavenging air pumps. However, to eliminate the scavenging pumps and reduce fuel consumption a pulse-type turbocharging system was needed, and it would be several years before this feature would be successfully introduced (in 1951) on a B&W marine propulsion engine.

The Buechi syndicate had meanwhile been dissolved. Brown Boveri had built up its own turbocharger design department and also had its own test center and production facilities. The decisive move had been made from individual to industrial turbocharger manufacturing. First signs of a global turbocharger service network were also visible.

The period between 1945 and 1960 saw the final breakthrough for turbocharging, first for four-stroke engines and then, from 1951 onwards, also for two-stroke engines. Boost pressures increased slowly but steadily during this period, although sales activities initially centered on low-pressure supercharging, i.e. pressure ratios were about 1.5. The original VTR turbochargers could be equipped with either a low-pressure or a high-pressure compressor, but the latter was hampered by a restricted volumetric flow rate. Compressor development in the following years would erase this disadvantage, pushing the pressure ratio at full load steadily towards 3.

There were several important collaborations with engine builders during this period. These collaborations showed once again the importance of the relationship between engine builder and turbocharger supplier. The new technology had to be explained to the engine builders, who needed to know how to make the best use of the exhaust energy in pulse operation and, in many cases, even how the exhaust pipes were to be designed.

Strategic decisions

The post-war period saw several decisions taken that would set the pattern for the coming decades and which ultimately would play a key role in the worldwide market acceptance of the BBC turbocharger.

In 1958 a decision was made to enter into a collaboration that would be of great strategic importance for Brown Boveri. This was the granting of a licence to Ishikawajima-Harima Heavy Industries (IHI) in Japan to manufacture BBC turbochargers. IHI, which was then building engines under licence from Sulzer, went on to expand throughout Asia, and in doing so secured a dominant position for BBC turbochargers in that region.

Dorthe Maersk

Continuous refinement of turbocharging technology had, by the early 1950s, set the stage for the next pioneering act. In October 1952, the 18,000 tonne tanker Dorthe Maersk was launched. It was the first ship to be powered by a turbocharged two-stroke diesel engine (B&W, 6 cylinders). Dorthe Maersk was the first milestone in two-stroke marine turbocharging.

The focus shifts to Asia
The years between 1955 and 1975 were a time of tremendous upheaval for the shipbuilding

industry. During this period, half of the world's shipbuilding moved to Japan's yards, while western European shipyards' share went from 80% to less than 40%.

Shipbuilding booms

IHI wasn't the only foreign company manufacturing BBC turbochargers at this time. In the period from 1955 to 1975, Brown Boveri signed several significant licence agreements – a strategy that would continue into the late 1970s and 1980s with agreements between BBC and firms in China, India and South Korea, among other countries.

The VTR..0 was in its heyday, with overall turbocharger efficiency around 56%. Engines with BBC turbochargers were continually breaking records for output and efficiency.

Enter the VTR..1

New compressors with higher efficiencies and pressure ratios as well as increased throughflows were developed through the 1950s and 1960s. Higher pressure ratios meant higher speeds and increased axial thrust, for which improved bearing designs were necessary. Mountings were also reinforced. In 1970, compressors with an even higher throughflow were introduced and the gas outlet housing was enlarged. The turbine intake was also reworked.

All of these improvements were incorporated in 1971 in a new series – the VTR..1. From now on, Brown Boveri could offer turbochargers with an overall efficiency of almost 60% for a wide range of applications.

RR buttresses the lower end of the range

In 1968, three years before the launch of the VTR..1, Brown Boveri brought a new series of small turbochargers onto the market. Named RR turbochargers due to its radial turbine and radial compressor, it was developed for applications at and below the lower end of the VTR power range. The RR turbochargers were intended mainly for use with high-speed four-stroke engines. These engines progressed enormously throughout the 1970s, making further development necessary.

The VTR/VTC..4 turbochargers

By the mid-1970s the VTR..1 had taken the original VTR concept as far as it could go. A new turbocharger range with completely re-designed components was on the drawing board. Freed from the constraints imposed by the first VTR, the VTR..4 ramped up efficiency by five percent and more, and increased the peak compressor pressure ratio to over 4. Following prototype tests on a Sulzer four-stroke engine, the VTC..4 turbochargers were successfully introduced to the market in the 1980s,

In 1980 a compact version featuring many of the VTR..4 turbocharger's VTC..4, it paved the way for Brown Boveri's collaboration with Caterpillar in the USA and also helped the company become a supplier to British Rail at the end of the 1980s.

In 1984 the efficiency of the VTR..4 was raised again. The VTR..4A managed peaks of 70 percent, largely thanks to improvements to the inducer wheel made possible by "three-dimensional" manufacturing.

Change of name

In 1988 ASEA and BBC merged to form ABB. In accordance with the new company's policy of decentralization, ABB Turbo Systems Ltd was set up in the following year to handle the turbocharger business. The worldwide reputation of the BBC turbocharger passed to the ABB turbocharger.

THE MODERN ERA BEGINS

The TPS/TPL generation leap

In the early 1990s ABB began to develop a new generation of more compact, lighter high-performance turbochargers as successors to the VTR, VTC and RR. Two new families, the TPS for engine ratings from 500 to 3,000 kW, and the TPL for engine applications with outputs from 2,500 kW up to the highest in the business, were designed from the ground up.

Fast-changing market conditions and compressor design potential dictated a fast pace for development work around the mid-1990s. It was concluded that the demands of the advanced engines being built at the time would best be met by two different compressors. The decision was therefore taken to introduce the TPS turbocharger with the new D-compressor for pressure ratios up to 4.2 at maximum continuous rating, and the equally new E-compressor for pressure ratios up to 4.5. These compressors have splitter bladed impellers for high airflow rates and backswept blades at the exit for a wide compressor map. Peak compressor efficiencies of more than 84% can be achieved.

TPS..-E compressor and turbine

The TPS..-F raises the pressure ratio benchmark

The continuing trend in engine development towards higher specific power is being accompanied by an urgent need to reduce emissions, and this has led to most modern engines having some version of the Miller cycle incorporated in it. For these and future advanced engines, ABB has developed three new series covering the engine power range of 500 to 3,300 kW. The new compressors developed for the TPS..-F series allow a 15% increase in the flow rates that can be covered by a given impeller size.

TPS with variable turbine geometry

Developments in the diesel and gas engine markets also led in the mid-1990s to a version of the TPS with variable turbine geometry (VTG). One reason was the increasing popularity of single-pipe exhaust systems for diesel engines. When conventional turbochargers are used with these, part-load operation tends to be difficult, load response is poor and smoke and particle emissions can be high.

Gas engine performance had also been progressing impressively due to increased efficiency and bmep, high altitude capability and controlled air-to-fuel ratios. However, it was not possible to simply use conventional turbochargers with these engines, either. Solutions ranged from installing a waste gate or throttle mechanism to special matching of the turbocharger, but each had its drawbacks. Demand for a turbocharger that would solve the problem was especially strong in the 1,000 kW to 3,000 kW market segment.

Variable nozzle ring of a TPS57 VTG turbocharger

An “adjustable” turbocharger was seen to be the ideal solution for both types of engine. Apart from eliminating the losses occurring with a waste gate, a turbocharger with VTG is more flexible in applications with changing operating or ambient conditions. Precise control of the air-to-fuel ratio, so-called “lambda regulation”, is achieved with an innovative nozzle ring that enables the effective turbine area to be varied without any significant drop in turbine efficiency. The clearances for the movable nozzle blades are reduced almost to zero by springs that push the blades against the opposing casing wall.

The TPL debuts

The TPL concept was developed as a platform for large modern diesel and gas engines with outputs from 2,500 kW upwards. For this family, ABB’s engineers designed a new axial turbine family with the blade lengths and stagger angles needed to cover the entire volume flow range. The bearing assembly is also new. Its axial thrust bearing has a free-floating disc with profiles on both sides, rotating at about half the rotor speed. The thick oil films this produces provide extra-high resistance to wear. The non-rotating bearing bushes are centered in a squeeze oil damper. As a result of this new technology the bearing lifetime has been doubled.

TPL80 turbocharger

First TPL prototypes and field tests

A very extensive qualification program and performance measurements in the labs provided hard
evidence of the TPL's capabilities, but experience with the new series still had to be gained in actual engine operation. Between 1996 and 1999, TPL turbochargers were subsequently installed on various engines, including the Wärtsilä 12V38 and Caterpillar MaK 16M32.

The TPL..-A is launched

The first of the new-generation TPL turbochargers to be introduced to the market was the TPL..-A. This series was developed for modern medium-to-large four-stroke diesel and gas engines and became a runaway success soon after its market launch in 1996. Applications range from main and auxiliary engines for small and large vessels, respectively, to stationary diesel and gas power plants.

The TPL..-B takes on the two-stroke market

Launched in 1999, the TPL..-B turbochargers were developed primarily for large, modern two-stroke marine diesel engines with outputs from 5,000 to 25,000 kW per turbocharger. Worldwide demand for larger ocean-going vessels was strong and new, more powerful engines for them were under development.

TPL..-C – catering to future four-stroke applications

While the TPL..-A/B turbochargers meet the requirements of most engine applications, the four-stroke market continues to push for more output and lower emissions. ABB has made use of the TPL's modular platform to introduce new components and innovative technologies in a new series – the TPL..-C The factors driving the development of this brand-new turbocharger were therefore, besides economic and operational considerations, the rules set by bodies such as the International Maritime Organization (IMO) and World Bank calling for a reduction in NOx and particulate emissions.

A CENTURY OF PROGRESS

A proud past is worth nothing if it does not stimulate to do better. It was the commitment to doing better that made first the VTR.., the RR such a success, the new TPS and TPL generations their worthy successors. Growing demand for energy, rising fuel costs and stricter emissions legislation are having an important influence on engine development in the medium- and high-speed segment.

A100 & A200 for single stage turbochargers

ABB Turbocharging introduced the all-new A100 turbocharger generation as a significant step in the development of single-stage, high-efficiency, high-pressure turbocharging. Three A100 series set a new standard with highest compressor pressure ratios for the high-speed and medium-speed diesel and gas engine segments as well as highest efficiency at high pressure ratios for low-speed diesel engines.

A185-L turbocharger

The next generation of diesel and gas engines fully utilize the considerable potential of the A100-generation turbochargers. Ful-load pressure ratios of up to 5.8 in continuous operation with aluminium compressor wheels, at high efficiencies, set new benchmarks for power density in turbocharger construction and take the known limits of single-stage turbocharging a significant step further.

A200-L turbocharger

The A200-L's compressor stage has been optimized to enable significantly more additional volume flow. In comparison to previous models, the A200-L has up to 30% additional volume flow, which to date is fully the equivalent to one size smaller in a series of turbochargers. This increase represents a quantum leap never before seen in the turbocharging industry.

About Power2

Power2 two stage turbocharging technology is capable of producing pressure ratios as high as 8 and above. It is one of the major enabling technologies of strong Miller Cycles, which can substantially reduce emissions of oxides of nitrogen (NOx) from diesel engines, while also making possible enhanced power densities and fuel efficiencies.

On 4 stroke diesels it has been demonstrated that the turbocharger pressure ratios produced by ABB Turbocharging's Power2 technology are high enough to achieve Miller Cycles capable of giving very high double digit NOx reduction percentages on 4-stroke diesel engines.

New products for a new era

The steady improvement in turbocharger and engine efficiency over the years has always relied on close cooperation between ABB and the leading engine-builders. It is this cooperation that sets the development goals and which will, in all probability, become closer as the demands made on the "turbocharging system", and not just the turbocharger as a component, increase. The price of oil, at a level not seen for years, is focusing attention once again on the turbocharger's traditional role as a fuel saver. Market demand for higher boost pressures and efficiencies, plus the need to reduce the environmental impact of marine traffic, requires advanced turbochargers. With its state-of-the-art development, test and production facilities, ABB Turbo Systems is well placed to supply them.

Milestones

1905
Alfred Buechi patents his idea.

1924
The first BBC exhaust gas turbocharger is delivered.

1930s and 40s
Development of the VTR series.

1950s

MS Dorthe Maersk is launched as the first ship with a 2-stroke, turbocharged diesel engine.
BBC sets up a turbocharger division with its own factory.
A license agreement is reached with Ishikawajima-Harima Heavy Industries (IHI) of Japan.

1960s

The RR turbocharger series is introduced.

1970s and 80s

Development of new V TR generations raises efficiency to over 70 %.
BBC becomes ABB Asea Brown Boveri. ABB Turbo Systems Ltd is founded as an ABB subsidiary. Hyundai Heavy Industries (HHI) of Korea receives a license to build ABB turbochargers.

1990s

The VTR series is enlarged. Parallel to this, ABB Turbo Systems develops the new-generation TPS and TPL series. ABB Turbo Systems and IHI set up a joint venture company, Turbo Systems United (TSU), in Japan.
The first ABB turbocharger with variable turbine geometry (V TG) is launched.

Since 2000

TPS and TPL become runaway successes.
The new Turbocharger Service Center in Baden is opened.
ABB develops and builds the world’s largest and most powerful turbocharger.
ABB Turbo Systems and Jiangjin Turbocharger Plant (JTP) set up ABB Jiangjin Turbo Systems Co., Ltd. as a joint venture company in China. More than 1000 units leave Baden factory in one month.
The A100 generation is launched as a new benchmark in single stage turbocharging. The global service network opens its 100th Service Station.
Production begins at new turbocharger factory in Klingnau. Introduction of Power2 two stage turbocharging.