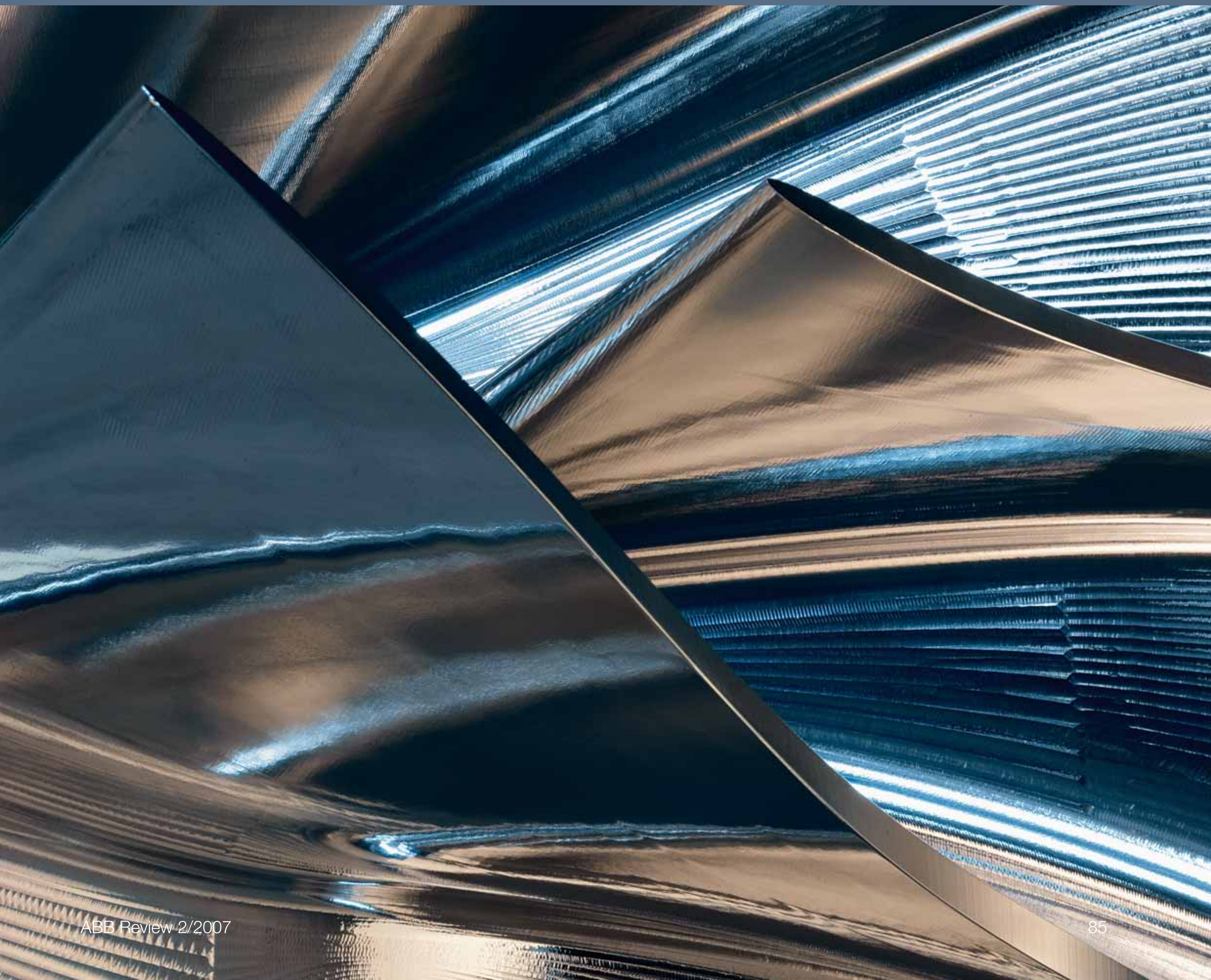
ABB turbochargers – history and milestones

Malcolm Summers

ABB exhaust gas turbochargers are hard at work all around our planet – on the world's oceans and high in the Himalayas, from the icy Arctic wastes to the simmering Australian outback. Out of an idea born a century ago has grown a high-tech product that is efficient and reliable in the extreme.



PERPETUAL PIONEERING

Like so many other innovative ideas before and since, the exhaust gas turbocharger was initially slow to progress after its announcement to the world in 1905. In a patent filed that year, Swiss engineer Alfred Buechi 1 described a "highly supercharged compound engine" with diesel engine, axial compressor and axial turbine mounted on a common shaft. While Buechi continued to develop his idea, inventors elsewhere were having some success with mechanical superchargers. But Buechi had like-minded competitors, too. By 1920 small exhaust gas turbochargers were being used in aircraft in France and the USA. Heavy-duty turbochargers were not yet considered to be economically viable.

1 Alfred Buechi. His 1905 patent is recognized as the starting point for exhaust gas turbocharging.

Progress at last

Things changed in 1923 with the publication in Germany of a report on successful low-pressure supercharging trials with a four-stroke diesel engine. Brown Boveri, one of the two founding companies of ABB, now made the decision to apply its extensive know-how in building turbines and compressors to the development of turbochargers.

> The period between 1945 and 1960 saw the world's merchant fleet double in size, and marked the final breakthrough for turbocharging.

That same year Swiss Locomotive and Machine Works (SLM) had a two-stroke experimental engine under test which needed bringing up to a higher power level with better fuel consumption. Brown Boveri recommended using an exhaust gas turbocharger that would feed into the scavenging blowers, and SLM subsequently placed an order for such a machine. In June 1924 turbocharger VT402, the world's first heavy-duty exhaust gas turbocharger, left the Baden works of Brown Boveri 2.

Interest was also high in the maritime community. One year earlier, in 1923, the Vulkan shipyard in Germany had ordered two large passenger ships, each to be powered by two turbocharged 10-cylinder, four-stroke MAN engines. The turbochargers were designed and built under Buechi's supervision. Launched in 1926, these two ships were the first in maritime history to have turbocharged engines.

The "Buechi Syndicate"

In 1925 Buechi took out a new patent in his own name that would win him world-renown. Detailing the advantages of pulse operation for low-pressure supercharging, it was the breakthrough that everyone had been waiting for. A new company, popularly known as the "Buechi Syndicate"[1)], was set up the following year. Buechi was put in charge of engineering and customer relations, Brown Boveri was to build the turbochargers and SLM would provide the diesel engines for tests and trial runs.

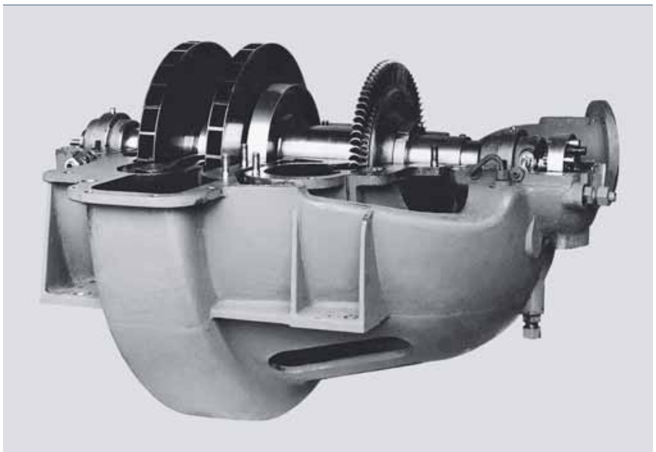
An improved, larger turbocharger designated VT592 was supplied to SLM in 1927 for a second experimental engine. The results were impressive. Licensing agreements were now being concluded between the syndicate and leading engine manufacturers. First test runs on diesel-electric locomotives took place 3. Turbochargers were also recommending themselves for more economic operation of stationary diesel power plants.

In 1932 specifications were formulated for a standardized range of turbochargers. Nine sizes were chosen, cor-

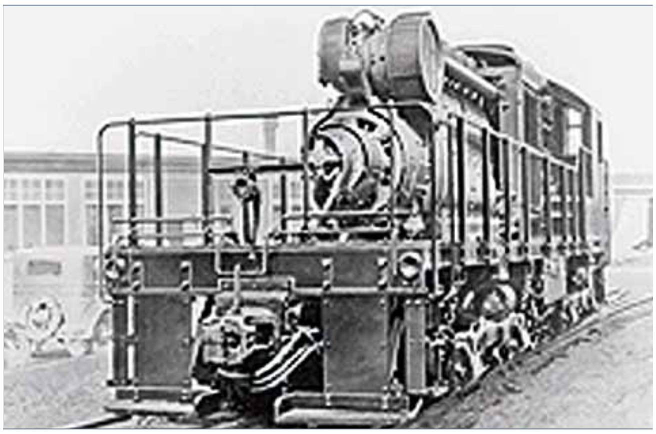
Footnote

1) The syndicate was dissolved in 1941.

2 World's first turbocharger for a large diesel engine, delivered in 1924



3 This ALCO 8-cylinder, 900 horsepower engine was typical of the engines being supercharged by Brown Boveri in the late 1930s (here with a VTx 350).



responding to compressor diameters from 110 to 750 mm. Wide use of modules and as many standard parts as possible allowed fitting to an enormous range of engines. Design features included externally mounted ball bearings, which made service work considerably easier.

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. The market introduction of the VTR..0 series in 1945 is a significant milestone in the BBC/ABB turbocharger story. With a compressor efficiency of 75 percent for a pressure ratio of 2, it was only the start of what was to come, but the VTR..0 marked the beginning of a new era 4.

Turbocharging's triumphant march

The period between 1945 and 1960 saw the world's merchant fleet double in size, and marked the final breakthrough for turbocharging. Boost pressures increased slowly but steadily during this period. 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.

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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. Built by the Danish shipyard A. P. Møller, it was the first ship to be powered by a turbocharged two-stroke diesel engine (B&W, 6 cylinders). Two VTR630 side-mounted turbochargers raised the engine's output from 5530 to 8000 horsepower. Dorthe Maersk was the first milestone in two-stroke marine turbocharging.

There were several important collaborations with engine builders during this period, showing once again the importance of the relationship between the engine OEM and turbocharger supplier. It was important to explain the new technology and how to make the best use of the exhaust energy in pulse operation, especially how the exhaust pipes were to be designed.

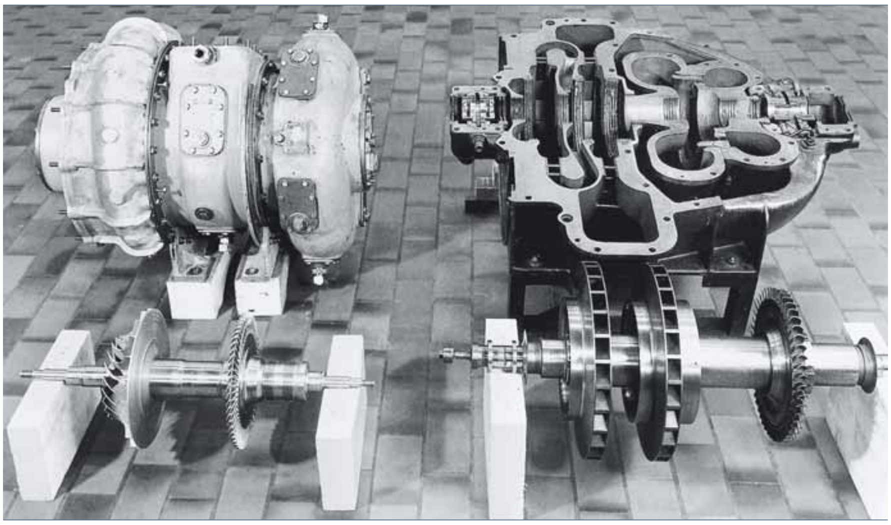
From 1955 on, Brown Boveri signed a number of important licence agreements. One was to have special significance: In 1958 a licence was granted to Ishikawajima-Harima Heavy Industries (IHI) in Japan to manufacture BBC/ABB turbochargers. IHI, which was then building engines under licence from Sulzer, went on to expand throughout Asia, and in doing so secured a dominant position for ABB turbochargers in that region.

Shipbuilding was now at a record level, crude oil prices were low and fuel costs had become insignificant. The diesel engine industry was booming. The VTR..0 was in its heyday, with overall turbocharger efficiency at around 56 percent. Engines with BBC/ABB turbochargers were continually breaking records for output and efficiency.

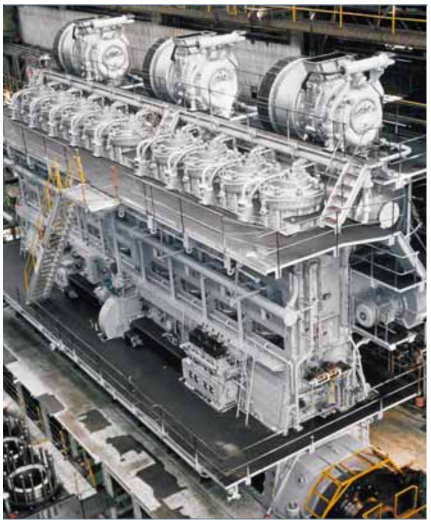
Enter the VTR..1

The 1950s and 1960s saw the development of new compressors with higher efficiencies and pressure ratios as well as increased air flow rates. Bearing designs were improved and mount-

4 Progress of turbocharger technology from 1924 to 1945. Designed for the same engine size, the more compact VTR320 on the left achieves a much higher boost pressure than the earlier VT402.



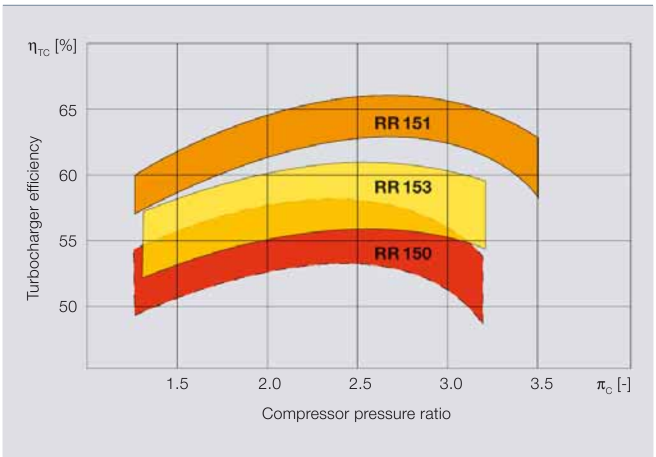
5 Sulzer 32,400 horsepower 9 RLA90 two-stroke diesel engine with three VTR714 turbochargers, manufactured by IHI, Tokyo



ings were reinforced. In 1970, compressors with an even higher air flow rate 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 percent for a wide range of applications. In the past, efficiency had risen steadily but slowly. This was the first big leap.

6 RR..1 turbocharger with mixed-flow turbine and compressor wheel with backswept blades



VTR..4 gives a further boost

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. Following prototype tests, the VTR..4 was introduced to the trade press in late 1978 and launched on the market the year after. Freed from the constraints imposed by the first VTR, it ramped up efficiency by five percent and more and increased the maximum compressor pressure ratio to over 4. The VTR..4 contributed to the spectacular rise in thermal full-load efficiency of large engines at this time from 38–40 percent to peak values of 44–46 percent 5.

The need for a compact version with as many of the VTR..4 turbocharger's components as possible was answered in 1980 with the VTC..4. This opened up new opportunities in the US market and was successfully deployed on locomotives in India, later also in China. Changing market conditions subsequently called for the development of an uncooled version of the VTR..4.

Another breakthrough came in 1985 with the RR..1 6. Mainly intended for high-speed four-stroke engines, the RR..1 set new standards of efficiency for small turbochargers, an area of business Brown Boveri had first entered seriously in 1968 with the RR150.

In the years that followed, the RR..1 contributed to the popularity of the high-speed engine in applications ranging from emergency gensets through marine propulsion to off-highway vehicles. Designed for an engine output range of about 500 to 1800 kW, it can also take much of the credit for the wide use of turbochargers on gas engines in Europe and in the USA.

Further development of the VTR..4 turbocharger was meanwhile also under way, producing peak efficiencies close to 75 percent with the VTR..4E in 1989 and pressure ratios of more than 4 with the VTR..4P, introduced to the market in 1991.

The TPS/TPL generation leap

In 1989, following the merger of ASEA and BBC to form ABB, ABB Turbo Systems Ltd was set up to handle the new group's turbocharger business. The change of name coincided with another development: Market studies in the mid-1980s had shown that new, benchmark turbochargers were needed in all the main areas of business. The engine-building industry was consolidating. Fewer, but stronger and more innovative companies were developing new generations of diesel and gas engines. For these engines, more efficient turbochargers capable of higher pressure ratios and flow rates were essential.

In the early 1990s, ABB began to develop a new generation of compact, lighter high-performance turbochargers as successors to the VTR, VTC and RR. Two new families, the TPS and the TPL, were designed from the ground up.

7 Container ships are an important market segment for the largest ABB turbochargers.

The TPS debuts

Since the launch of the first RR turbochargers in 1968, the high- and medium-speed diesel and gas engine market had been changing fast. ABB therefore set about developing an entirely new generation of small heavy-duty turbochargers in four frame sizes to cater to the foreseeable needs of this sector. Two compressors were initially developed, achieving pressure ratios of up to 4.5 and peak efficiencies of more than 84 percent.

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). An "adjustable" turbocharger was seen to be the ideal solution for diesel engines with the increasingly popular single-pipe exhaust systems as well as for gas engines, which require precise control of the air-to-fuel ratio, so-called "lambda regulation".

Launch of the TPL

The TPL turbocharger family was developed for large modern diesel and gas engines with outputs from 2500 kW upwards. For this range, ABB's engineers designed new axial turbines, a new, innovative bearing assembly and two new centrifugal compressor stages.

The first of the new-generation TPL turbochargers to be introduced to the market was the TPL..-A. This was developed for four-stroke diesel and gas engines in the power range of 2500 kW to 12,500 kW and became a runaway success soon after its market launch in 1996. Five frame sizes cover the requirements of applications that range from main and auxiliary marine engines to stationary diesel and gas power plants.

Three years later ABB launched the first of its TPL..-B turbochargers. These were developed primarily for the large, modern two-stroke marine diesel engines rated from 5000 to 25,000 kW (per turbocharger) being built for large ocean-going vessels 7.

The steady improvement in turbocharger and engine efficiency has always relied on close cooperation between ABB and the leading engine-builders.

Initially, four frame sizes were considered to be enough to satisfy market demand in the medium term. However, it was later decided to develop a fifth, even more powerful turbocharger (TPL91) to take account of shipbuilders' plans to build even larger "post-Panamax" container vessels. ABB's engineers were challenged once more: The turbocharger was to be designed for use on engines with power outputs in excess of 100,000 brake horsepower and yet still be compact. This was achieved by designing a new, shorter rotor and a new constant-pressure turbine and diffuser. Mounting of the engine was also made easier by an integrated oil tank 8.

A new turbocharger for the traction market

The TPL was also the basis for the TPR, a new railroad turbocharger launched by ABB in 2002. Designed specifically to meet demand for extra power and robustness as well as better environmental performance in traction applications, it features an integral high-efficiency turbine, an improved single-entry gas inlet casing and a unique foot fixation.

The pressure ratio benchmark is raised again

The continuing trend in engine development towards higher specific power is accompanied today by an urgent need to reduce emissions, and this has led to most modern engines having some version of the so-called Miller cycle[2)] incorporated. For these and future advanced engines ABB has developed the TPS..-F family 9. Three new series cover the engine power range of 500 to 3300 kW and achieve full-load pressure ratios of up to 5.2 with an aluminium-alloy compressor wheel.

The TPS..-F was also the first ABB turbocharger to feature recirculation

Footnotes

[2)] The basic principle underlying the Miller process is that the effective compression stroke can be made shorter than the expansion stroke by suitably shifting the inlet valve's timing. If the engine output and boost pressure are kept constant, this will reduce the cylinder filling and lower the pressure and temperature in the cylinders, thereby reducing the emissions.

8 Assembly of the TPL91-B turbocharger

9 TPS..-F turbocharger

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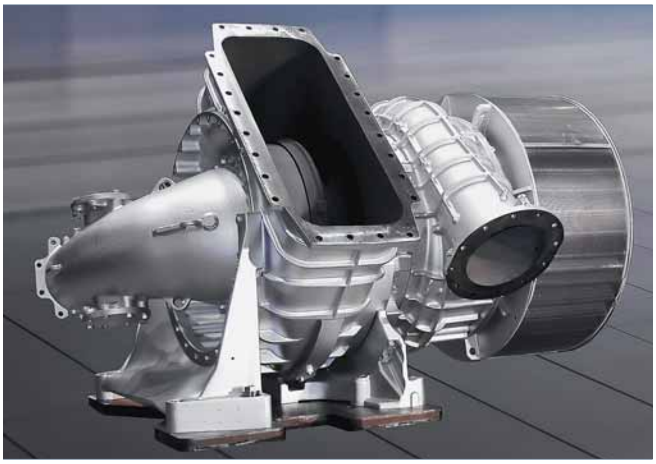
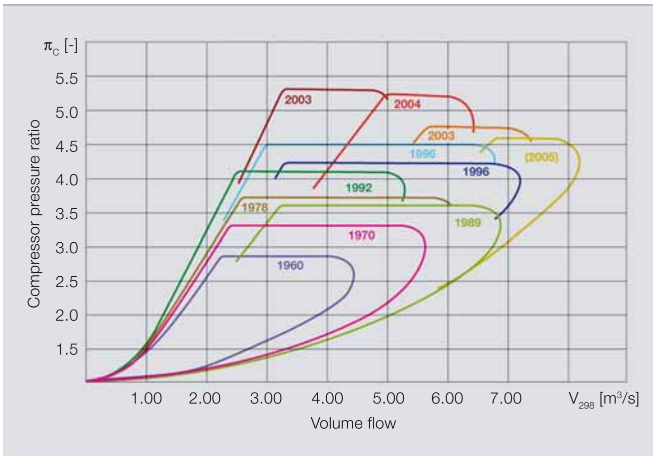
10 The TPL76..-C turbocharger has been developed for advanced four-stroke engines



11 Progress in the compressor performance of ABB turbochargers since 1960 (full load, with an aluminium compressor)



technology – a bleed slot around the compressor wheel which, by improving the flow field, increases the surge margin. The effect of this slot is to enlarge the map width without compromising the compressor's high efficiency.

A turbocharger for advanced four-stroke engines

The new millennium has seen the four-stroke engine market continue to push for more output and lower emissions. ABB therefore decided to make use of the TPL's modular platform to introduce new components and innovative technologies in a new series – the TPL..-C – that caters especially to this future market 10.

Developed for advanced four-stroke, medium-speed diesel and gas engines in the power range of 3,000 to 10,000 kW (per turbocharger), the TPL..-C offers two different turbines: one for quasi-constant pressure as well as pulse-charging systems, and one specifically for quasi-constant pressure systems. An innovative feature of the compressor is optional air cooling. This extends the field of application for aluminium alloy wheels, offering users an economic alternative to titanium impellers when very high pressure ratios are required.

Factbox 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 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.

The engine's exhaust gas, at approximately 600 °C, is directed at high velocity onto the blades of a turbine, which drives a compressor wheel mounted on the same shaft. As it rotates, the wheel sucks in air through a filter-silencer, compresses it and feeds it via an after-cooler to the air receiver, from where it passes to the cylinders.

A century of progress

In the 100-plus years since Buechi's 1905 patent[3], the exhaust gas turbocharger has become indispensable to the diesel and gas engine industry. Investment in research and development over the decades has brought quantum leaps in technology and design – well documented by the progress demanded, and achieved, in turbocharger performance over the years 11.

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The steady improvement in turbocharger and engine efficiency 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.

In the technologically advanced TPS and TPL turbochargers, ABB has worthy successors to the highly successful VTR and RR series. With the market continuing to demand higher boost pressures and efficiencies, not least because of the contribution they make to reducing engine emissions, the future belongs to turbochargers that combine these qualities with highest performance and long times between overhauls.

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Footnotes

[3] A complete history of the BBC/ABB turbocharger can be read in the centenary issue of Turbo Magazine, no. 2/2005, published by ABB Turbo Systems.