The New A100-H Single-stage Turbocharger Series for High-speed Engines

With the new A100-H turbocharger series, ABB Turbocharging sets an important milestone in the development of efficient, single-stage high-pressure turbocharging systems. The new series allows highest performance in the modern high-speed diesel and gas engine segment: compressor pressure ratios of up to 5.8 with aluminium compressor wheels at high turbocharger efficiencies. These characteristics, together with a range of other innovative features, take account of the operating requirements of future diesel and gas engines as well as the necessity to further reduce engine emissions.

1 Introduction

The worldwide increase in demand for energy, rising oil and gas prices and ever-stricter emissions legislation are having an important influence on engine development in the high-speed segment and therefore also on the development of new turbocharger technologies: the trend towards higher engine power densities and towards higher power output continues unabated. Higher mean effective pressures require a further increase in turbocharger pressure ratios. Optimization of combustion technology, further development of engine-internal measures as well as the increasing importance of exhaust aftertreatment systems, also determine the development of modern turbocharging systems. To utilize the available resources as sparingly as possible and thereby reduce fuel consumption, energy-efficient engines, and consequently highly efficient turbocharging systems, are essential.

High compressor pressure ratios are required today not only to increase the power output, which was the key aim in the past, but also because they play a significant role in emissions reduction. A higher pressure ratio is necessary in order to introduce the Miller/Atkinson process, even with a more moderate increase in power output. The Miller/Atkinson process is used in some form in almost all diesel and gas engines. While it contributes in diesel engines to a reduction in the NO_x emissions, in gas engines it is used to shift the point at which knocking begins. Extra reserves of pressure ratio are also required for engines operated at high altitudes.

During the last ten years the mean engine power output in the high-speed segment could be increased by about 50 %, while the specific fuel consumption has gone down by some 10 % and the engine emissions could be lowered by up to 80 %, **Figure 1**. Over the same period, the technical demands made on the turbochargers have risen, by comparison, quite remarkably. Using the compressor power at the engine design point for the given compressor pressure ratios and flow capacity as a yardstick, it is seen that the required thermodynamic and mechanical performance of the turbocharger has risen markedly.

Ten years after their introduction, more than 25,000 TPS series turbochargers are successfully operating on small medium-speed diesel engines and on large high-speed diesel and gas engines rated from 500 kW to 3,300 kW. While the TPS turbochargers continue to be the preferred choice for engine series rated at today's power levels, demand for ever-higher engine power densities and higher efficiencies, as well as the need to curb engine emissions, has led to the development of the new A100-H turbocharger series for future engine concepts.

Figure 2 shows the development of the mean effective pressures as well as of the compressor pressure ratios required by high-speed diesel and gas engines. Gas engines typically require higher pressure ratios than diesel engines on account of the higher control-related system losses and their different fuel management. The next generation of diesel and gas engines will fully utilize the considerable potential of the A100 turbochargers. Full-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.

2 Design Concept

To meet future engine-builder demand for higher compressor pressure ratios

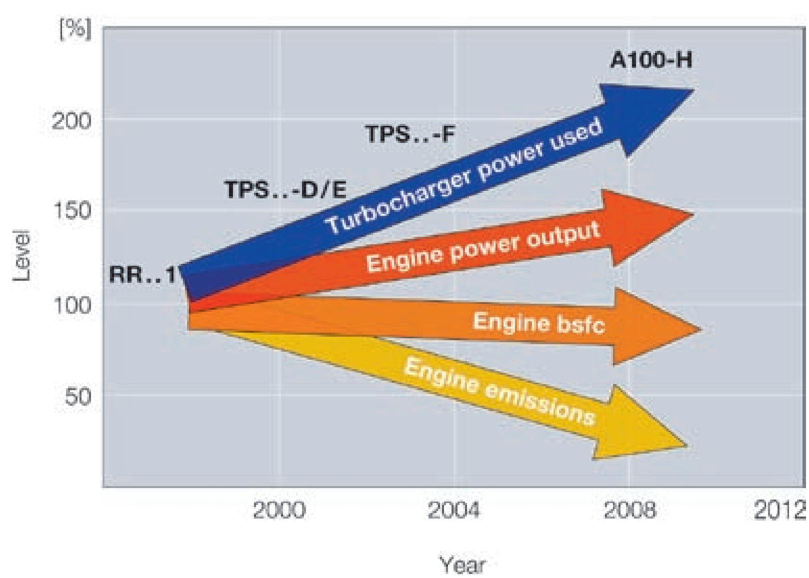

Figure 1: Increasing demands made on turbocharger performance

The Authors

Dr.-Ing. Dirk Wunderwald is general manager of the "High-Speed Segment" sales department at ABB Turbo Systems Ltd in Baden (Switzerland).

Tobias Gwehenberger heads the "Small Turbocharger Engineering" group in the engineering division and is also in charge of the development project "A100-H/M" of ABB Turbo Systems Ltd in Baden (Switzerland).

Dr.-Ing. Martin Thiele is general manager in charge of "Product Line Small Turbochargers" in the engineering division of ABB Turbo Systems Ltd in Baden (Switzerland).

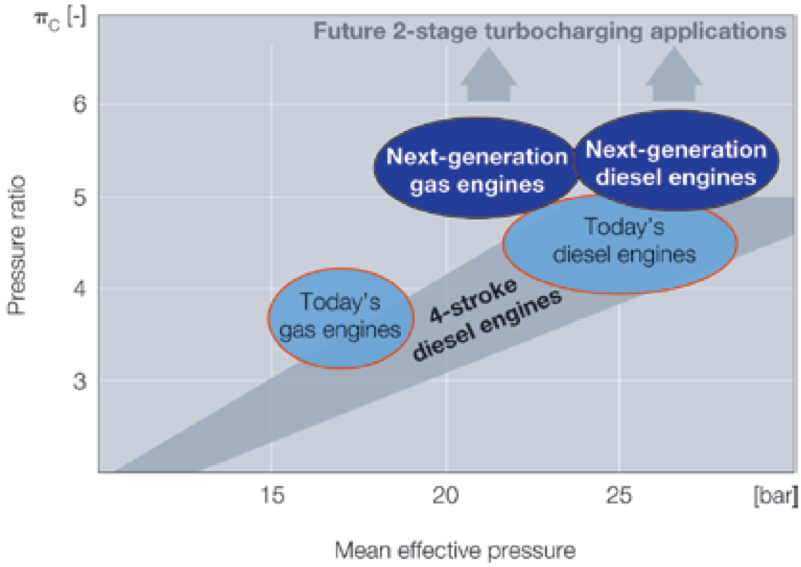

Figure 2: Trends in the turbocharging of modern engines

with single-stage turbocharging, ABB has developed a new high-pressure turbocharger series. The four frame sizes of the A100-H series have the same outer dimensions as the field-proven TPS turbochargers and, also like the TPS, have the oil inlet and outlet ducts integrated in the foot. It is thus ensured that in the case of further development of current TPS-turbocharged engine platforms, these engines can be fitted with new-generation A100 radial turbochargers without any major changes to the turbocharger mounting.

The A100 radial turbochargers, like the TPS..-D/E and TPS..-F generations before them, are of modular construction with a minimized number of component parts. The design of these compact and robust turbochargers allows matching to the particular requirements of each diesel and gas engine application. Alongside the A100-H series for high-speed engines ABB is also launching the A100-M radial turbocharger series, developed for small medium-speed engines. Options which can be chosen include coated nozzle rings, multi-entry turbine inlet casings or different casing materials for different turbine inlet temperatures. A range of specific design and configuration features enables the turbochargers for medium-speed engines to also be used with HFO and with pulse turbocharging systems.

During development of the A100 radial turbocharger, particular attention was paid to the continued use of aluminium for the compressor wheels, so as to avoid having to use cost-intensive titanium components. ABB developed and put into series production a cooling technology especially for the A100 series which allows even at very high pressure ratios of up to 5.8 the operational reliability and long component exchange intervals users have come to expect with aluminium compressor wheels.

The compressor wheel cooling is designed in such a way that heat transfer to the space behind the wheel is practically eliminated and the heat transferred to the wheel itself is reduced. This was achieved through a combination of advanced CFD and FE analysis. Cooling with compressor air was shown by an extensive test program to be the most efficient solution and also to be the easiest and least costly for the engine builder to implement. Depending on the specified compressor stage, a small fraction of the compressor mass flow is tapped off after the charge air cooler and fed back to the compressor for cooling.

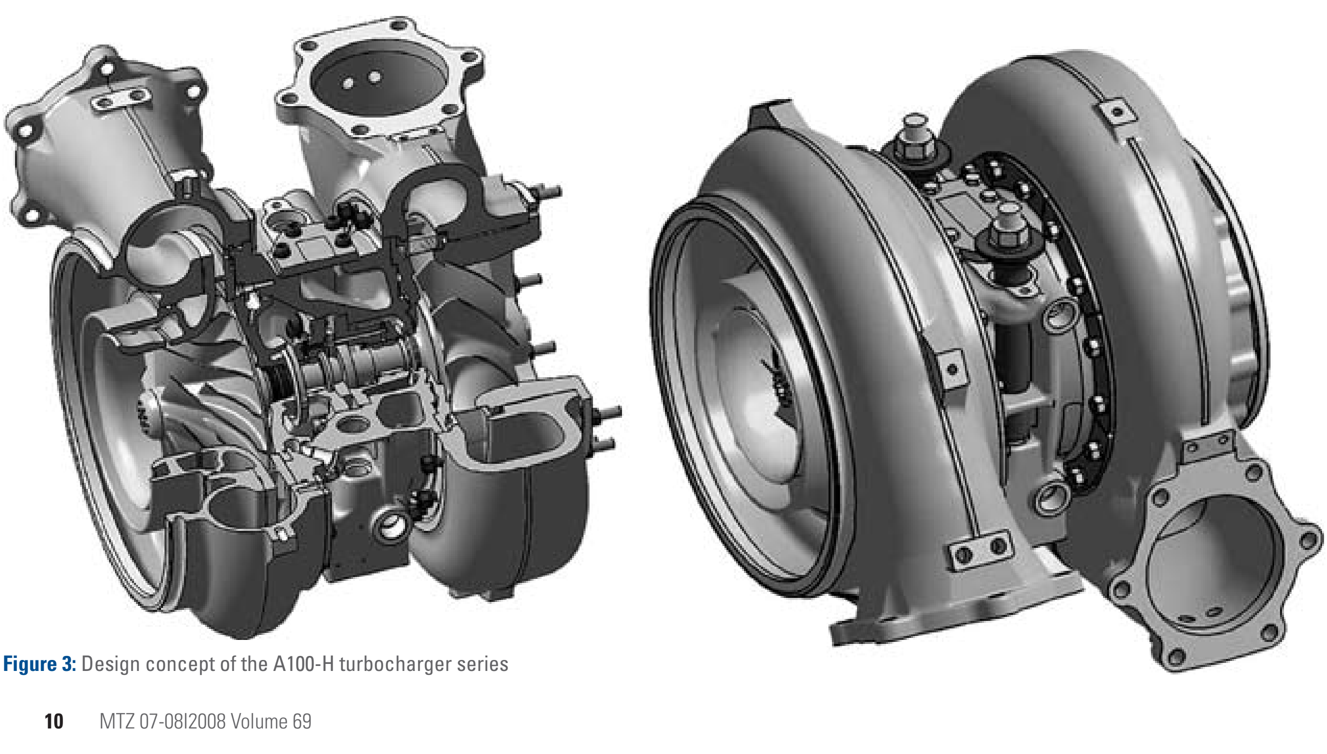

Figure 3: Design concept of the A100-H turbocharger series

The low-stress construction of the individual casings takes account of the much higher mechanical demands made on them. During the design of the casings ABB worked closely with the engine builders to ensure the same compactness as the TPS as well as optimum mounting of the turbocharger on the engine console, **Figure 3**. For example, the bolts used to fasten the new A100 radial turbocharger series to the engine are easily accessible and can also be tightened hydraulically. Mounting of the A100 turbocharger has also been made easier by positioning the bolts in the upper part of the bearing housing, Figure 3. The casing construction was optimized with the help of advanced numerical design software, which was also used in the design of an optimal containment concept. The safety of the containment, a vital consideration in view of the significantly increased power density of the new turbochargers, was confirmed both numerically and experimentally by turbocharger containment tests on the test rig.

The increase in maximum power density that results from the higher achievable pressure ratios of the new turbochargers has led to the shaft design being strengthened. The design concept for the A100 shaft bearing assembly was based on the successful TPS bearing technology; the seals in the area of the rotor components and bearing assembly have been further developed. The stronger shaft was also a factor in the design of the bearing assembly, where the losses have been kept low. On the turbine side the casing centring concept which has proved so successful with the TPS..-F has been retained and ensures safe and efficient turbocharger operation. This concept minimizes temperature-related casing eccentricity, allows very small operating clearances and practically eliminates the risk of rubbing even at the highest turbine inlet temperatures.

3 Thermodynamic Performance

3.1 Compressor Stages

Three completely new compressor stages, each with different compressor wheels (i.e. different blading), were designed for future engine applications. This allows the compressor volume flow range of today's TPS..-F turbochargers to be covered by the new A100-H turbochargers with significantly higher pressure ratios. **Figure 4** shows the full coverage of the pressure ratio versus volume flow range for the A100 radial turbochargers in a comparison with the curves for TPS..-F turbochargers at full load. For certain specifications even higher values can be achieved.

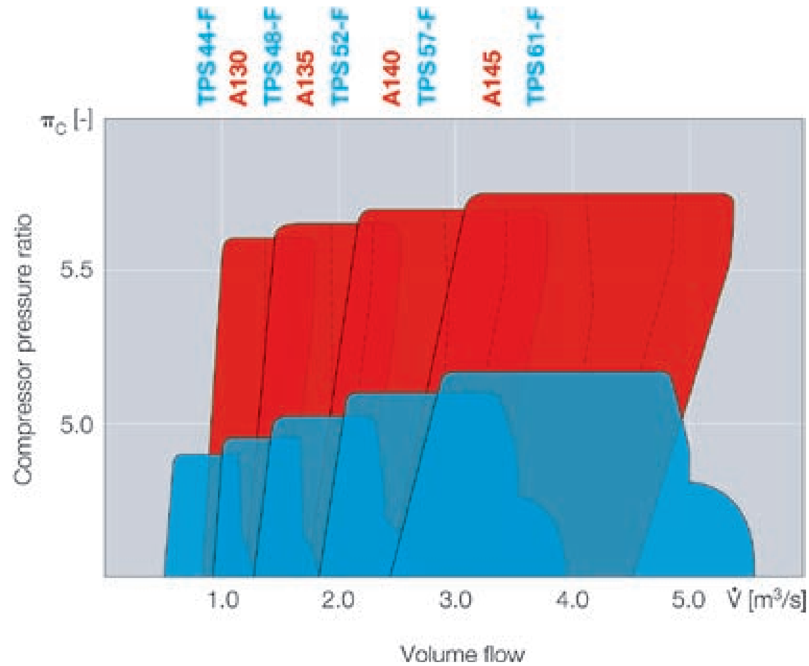

Figure 4: Pressure ratio versus volume flow range for A100 turbochargers at full load

The new A100 radial compressor stages feature, like the TPS compressor stages, a single-piece aluminium compressor wheel. In order to achieve full-load pressure ratios of about 5.8 with aluminium wheels, new high-pressure diffusers and compressor blading had to be developed in addition to the compressor wheel cooling technology. The innovative wheel cooling also had to be taken into consideration during the development of the compressor stages due to its effect on the stability characteristics and on pressure build-up across the stages. The compressor maps show that high efficiencies are achieved, that the map widths are excellent and that there are adequate overspeed margins even at high pressure ratios. A range of compressor stages is available for every turbocharger frame size, allowing optimal matching to every application. **Figure 5** shows, as an example, a compressor map based on measurements on an A140-H turbocharger. 80 % compressor efficiency is achieved on a typical generator line for a full-load pressure ratio of 5.8.

Since the higher centrifugal forces and material temperatures increase the mechanical loading of the compressor wheels, it was also necessary to look at new ways of confirming the blade vibration safety. During the mechanical design of the new stages comprehensive FE stress and natural frequency calculations were therefore carried out together with blade vibration measurements on the combustor test rigs. As a result it was possible to reduce vibration excitations over the extended operating range and also move critical eigenforms beyond the operating limits.

3.2 Turbine Stages

A new generation of mixed-flow turbines was developed especially for the new A100 turbochargers. Besides the existing TPS mixed-flow turbine stage, three completely new turbine stages are used with the A100 turbocharger series. These turbine stages are optimally matched, the centrepiece of each one being a turbine wheel designed precisely for the corresponding flow capacity. Whereas in the case of the existing TPS

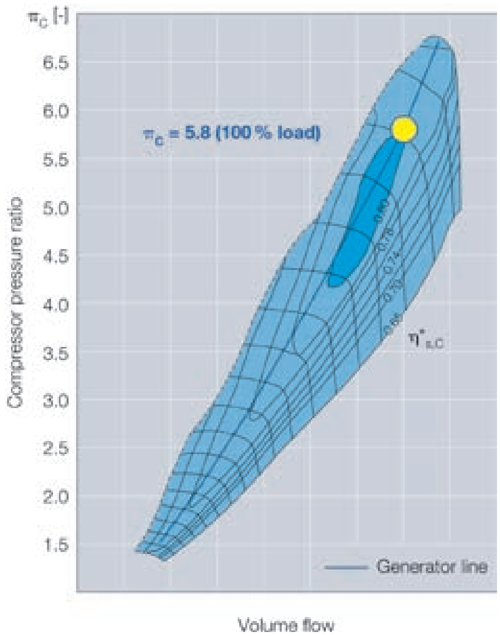

Figure 5: Compressor map (A140-H)

turbine stage the flow capacity is matched via the blade trim, the new turbine wheels feature individual blading configurations. By reducing the turbine mass and with it the mass moment of inertia this has allowed an improvement in acceleration performance.

A characteristic of the new mixed-flow turbine family is a larger operating range. With these turbines the new compressor stage's high pressure ratio potential can be exploited over an even wider range of application. Due to the optimal design in each specific volume flow range, the individual stages exhibit higher turbine efficiencies than the current TPS turbine stages. Further development of the sealing technologies has reduced the bypass flows so that flow losses are lower. This has allowed, in particular, a substantial improvement in turbocharging performance at higher boost pressures, **Figure 6**.

Another advantage of the new turbine stages is their improved burst behaviour in the event of high overspeed up to the natural burst speed. The blades of the new turbine family used in the A100-H would fail first. This minimizes the burst energy that is set free, compared with the current TPS turbine stage, which would experience hub failure at the natural burst speed. Bursting of the A100 hub at the natural burst speed can be excluded due to the A100 blading's failure mechanism. The burst performance was dimensioned with the help of advanced FE analysis. To confirm the simulation results burst tests were performed with turbine wheels at over 600 °C in a spin tank. The burst mode seen in the tests agreed very closely with the calculated results.

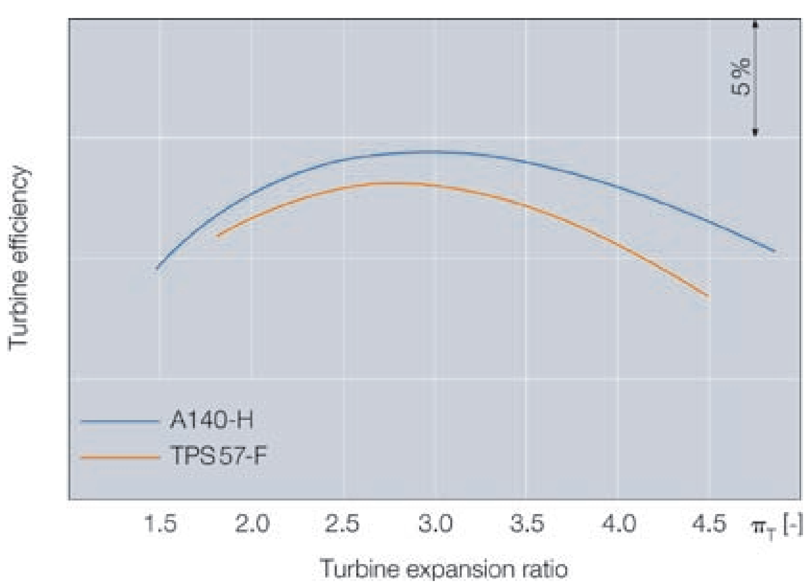

Figure 6: Turbine efficiencies, A140-H and TPS57-F

3.3 Turbocharger Performance

A wide range of available compressor and turbine specifications makes the A100 series ideally suited for applications on engines in the marine, industrial and power generation as well as traction sectors. **Figure 7** shows the outstanding thermodynamic potential of the A100 series in the case of a full-load-optimized turbocharger specification. The comparison with turbocharger efficiencies of the RR and TPS generations illustrates well the performance gain precisely in those engine applications making very high demands on the achievable compressor pressure ratio, and therefore the quantum leap the A100 represents in turbocharger development for single-stage turbocharging of modern high-speed engines. By choosing the right turbocharger components, the optimum efficiency could be shifted in the direction of lower compressor pressure ratios. This allows, for example, excellent performance characteristics to also be ensured for ships' propulsion engines.

4 Mechanical Qualification Program

A comprehensive qualification program was carried out with the A140-H on ABB's own combustor test rigs to ensure the reliable operation of the new A100 generation in future engine applications. The tests cover on the one hand thermodynamic checking of the new compressor and turbine stages, and on the other mechanical qualification of the new component parts.

The qualification program for the individual components is based on years of experience in the development of turbochargers as well as on field experience with ABB radial turbochargers. The standardized turbocharger tests, which include a very extensive program during the development phase, are obligatory for new developments at ABB Turbo Systems and follow precisely defined, internal process guidelines. The mechanical qualification covers all new components in the A100 series and consists of the following tests, among others:

- Checking of the HCF strength of the compressor and turbine stages
- checking of the rotor dynamics with the help of shaft motion measurements, with consideration taken of extreme bearing clearance and rotor unbalance
- checking of the load capacity of the axial bearings under extreme thrust loading
- oil tightness tests on the compressor and turbine sides, at standstill and during idling, taking into account maximum permitted oil pressures and temperatures
- emergency stop tests with and without water-cooled bearing housing
- thermal cycle tests for turbine-side components
- containment tests on both the compressor and turbine sides at compressor overspeed and at the natural burst speed of the turbine.

In addition to the above, the individual rotor components and the complete turbocharger are put through other severe tests. Only after successfully passing the entire qualification program is a product release certificate issued for newly developed turbochargers.

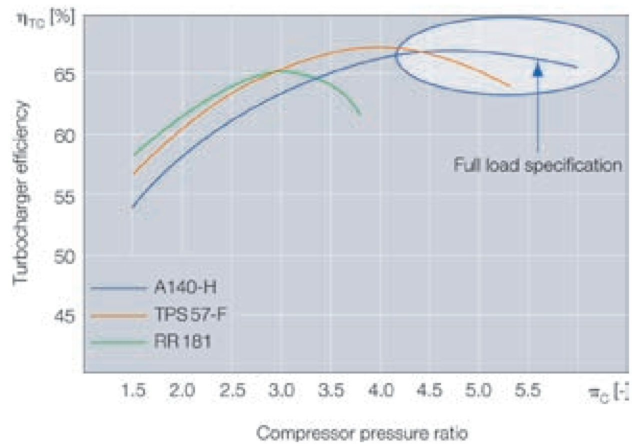

Figure 7: Turbocharger efficiency of A140-H with full-load-optimized specification

4.1 Qualification of the Radial Journal Bearings

The new A100 turbochargers are designed to be operated in high-pressure, continuous duty applications at higher speeds than the TPS turbochargers. The newly developed compressor and turbine stages accordingly exhibit different mass moments of inertia to the previous TPS components. In order to investigate the rotor dynamics of the new components at speeds beyond the current TPS speed range, extensive shaft motion measurements were performed on the A100 radial bearing assembly at speeds of up to 120 % overspeed. These measurements took place at different oil inlet pressures and temperatures as well as with different rotor unbalances. **Figure 8** shows, as an example, the measured shaft motion amplitudes for high rotor unbalance versus the turbocharger shaft speed. The very low measured shaft motion, compared with the maximum possible radial motion (100 %) of the shaft, underlines the expected high reliability of the A100 bearing assembly. The combination of new radial bearing assembly and new compressor and turbine stages displays, as does the TPS radial bearing assembly, excellent stability characteristics up to the required high operating speeds.

4.2 Emergency Stop Tests

To ensure that the new turbochargers also run trouble-free in the case of an emergency shutdown of the engine, comprehensive emergency stop tests were carried out with the A140 on a combustor test rig. These involved the turbocharger being stopped suddenly when running at full load with the maximum permitted gas inlet and outlet temperatures, accompanied by simultaneous shutdown of the oil supply. The tests were carried out both with and without additional after-cooling. The material temperatures in the turbine-side journal bearing and in the relevant casing parts were recorded for the full duration of the shutdown.

Trouble-free turbocharger operation after either a normal shutdown proce-

Figure 8: Results of shaft motion measurements during radial bearing qualification

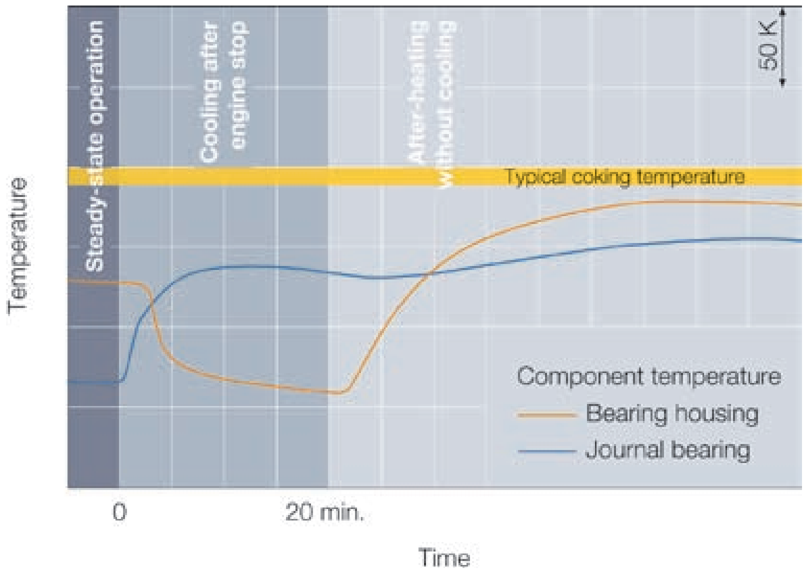

Figure 9: Results of material temperature measurements during emergency stop test

dure or an emergency stop depends primarily on the maximum material temperatures in the journal bearings and in the casing parts wetted by lube oil being as low as possible. This can prevent premature journal bearing wear as well as slow down the deterioration of the oil. In the case of the A100 turbochargers it is achieved by optimized water cooling of the bearing housing. The relevant material temperatures in the journal bearings and in the casings are maintained at a low level even during the after-heating phase – an especially important issue for gas engine applications with high turbine inlet temperatures. Water cooling can be ensured in the case of an emergency stop by after-run pumps or by using the thermosiphon effect.

Figure 9 shows the material temperature curves in the turbine-side journal bearing and in the bearing housing after an engine shutdown. After steady-state operation, followed by an engine stop, there is a subsequent 20 minute period during which the bearing housing is cooled. The material temperatures remain below the typical oil coking temperature range even during the after-heating phase, in which no further cooling takes place.

The material temperature curves in Figure 9 were recorded for a maximum turbine inlet temperature of 710 °C and a maximum oil inlet temperature of 105 °C. The inspections after the emergency stop test showed that the journal bearings as well as the shaft journals themselves remain in good condition even in the case of an emergency stop without after-cooling.

5 Introduction Program and First Results on Engines

Mid-2007 saw the first A140-H prototypes successfully commissioned on ABB's test rigs. The first frame size of the new turbocharger series successfully completed the rigorous qualification program and has meanwhile been released for series introduction. ABB will introduce the other frame sizes to the market at intervals of a few months, with the complete A100-H series available for series production by the middle of 2009.

In the run-up to the series introduction of the A140-H the thermodynamic performance was thoroughly tested and verified by means of a series of engine test rig trials using technology demonstrators and A140-H prototypes. Due to the high pressure ratios and efficiencies that can be achieved with the A140-H it was possible to clearly demonstrate the high power densities expected on the engine side. Several thousand running hours on the test rig have also confirmed the high performance level of the A100-H series in continuous operation. In the meantime, the first turbochargers of the new series have been delivered for trials on selected field installations. Engine trials with the next frame sizes are already successfully under way.

The maintenance intervals for the A100-H turbochargers have been kept similar to those for the proven TPS turbochargers. Although the demands made on thermodynamic and mechanical performance are higher, the turbochargers of the new A100 generation will satisfy all requirements in respect of high reliability and low-maintenance operation. The necessary service know-how and logistics support for the new turbochargers is ensured by an excellent network of some 100 service stations around the world.

6 Summary

The development of the new A100-H turbocharger series was determined by the demands made on future high-speed diesel and gas engines. The ongoing trend towards even higher power outputs and the stricter emissions regulations call for a further increase in pressure ratio at high efficiencies. With their outstanding full-load performance, the new A100-H turbochargers set a significant new benchmark for single-stage turbocharging.

The completely new A100-H turbochargers are characterized by a compact and robust construction. A series of technological innovations and numerous optional features allow optimum matching of the A100-H for turbocharging modern engines. In addition to the A100-H series for high-speed engines, the A100-M radial turbocharger version for small medium-speed engines is being introduced to the market.

The comprehensive qualification program and numerous engine tests have been successfully concluded and the first frame size, the A140-H, has been released for market introduction. The first turbochargers of the new series have been delivered for selected field installations and are meanwhile undergoing field trials. Further frame sizes will be introduced by mid-2009 for the turbocharging of advanced diesel and gas engines. ■

Gestaltung: büdesignbüro

news, texte, blogs, forecast:
www.lightweightdesign.de

Simply fill in the coupon and **fax** to **0611.7878-440** or send it by **post.**

Vieweg Verlag Leserservice | Abraham-Lincoln-Str. 46 | 65189 Wiesbaden | Fax: 0611.7878-440 | E-Mail: vieweg@abo-service.info

- ◯ Yes, please send me the trade magazine lightweight**design** immediately (6 issues + access to online archive) for at least 12 months for the subscription price of € 96 plus postage. This will give me online access to all editorial contents in English.
- ◯ Yes, please send me a trial copy of the first issue of lightweight**design** (Feb./March 2008).
- ◯ Yes, I would like to receive the lightweight**design** newsletter free of charge by e-mail.

First name ______

Surname ______

Company ______

Sector ______ Department ______

Address ______

Postcode / Town ______

Country ______

Tel. No. / Fax ______

E-mail ______

______
Signature/Date

Right of withdrawal: I have the right to cancel this agreement in writing within 14 days after the purchase order date at Vieweg Verlag, Leserservice, Abraham-Lincoln-Str. 46, 65189 Wiesbaden. It is sufficient if the cancellation is sent off before the end of the cancellation time limit. Vieweg Verlag, GF: Dr. R. Birkelbach, A.F. Schirmacher, AG Wiesbaden HRB 9754.

XXXX 311 07 040