State-of-the-art gas turbines – a brief update

Power market forecasts are confirming a strong upsurge of interest in gas turbines and combined cycle power plants. The trend is being driven by a range of benefits that include lower investment and power generation costs, shorter plant construction times, high availability and low emissions. Gas turbine development work in recent decades has created a platform that will enable manufacturers to meet the more rigorous demands being made on these machines. With the GT24 and GT26, ABB has both an innovative concept and the core technologies that will make it possible, in the near future, for combined cycle plants to achieve 60 percent thermal efficiency whilst complying with tough emission standards.

The first BBC industrial gas turbine to enter commercial service began its working life in a power station at Neuchâtel, Switzerland in 1939 [1, 2]. In the meantime, gas turbines have been employed for a wide range of applications besides power generation. The governing factor in each case has been the cost of the available fuel, ranging from residual, crude and light oil or even low-BTU blast furnace gas [3] for peak and base-load applications, to natural gas for modern base-load plants. Over the last 60 years, thanks to the innovative efforts of engineers and designers, the gas turbine has earned an impressive reputation for very good fuel flexibility.

A trend towards privatization in the power supply sector and widespread deregulation of the energy market are bringing about a major change in the power plant business. More than 30 percent of the power plants currently under construction are being built by independent power producers in competition with electric utilities.

At present, over 35 percent of the power generation capacity installed annually – a total of about 85 GW – is based on gas turbines. As more and more natural gas production sites come on stream, the price of this clean primary energy carrier will make it increasingly attractive. Ecological as well as economic benefits underlie the current preference for operating gas turbines together with steam turbines in combined cycles, involving large and small units as well as cogeneration plants. **1** shows, among other things, how the thermal efficiency of the gas turbine combined cycle plants has improved over the years. The reduction in nitrogen oxide (NO_x) emissions with natural gas used as fuel is especially impressive.

The current overcapacity in the GT manufacturing sector and strong competition in the new markets in Asia and parts of Europe have brought about a strong drop in the price of gas turbines and combined cycle facilities. In the past four years, market prices have fallen by approximately 50 percent. Because of this the design, production and assembly of gas turbines and combined cycle plant components have to be undertaken on a global scale, with strong local participation. Emphasis has to be on providing what the customers want at the right price [4].

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Demands made on gas turbines

The current market situation defines the following goals for the gas turbine suppliers.

- Larger units, ie increased unit rating and specific power
- Increased availability and lifetime
- Low initial investment and maintenance costs
- Increased total efficiency
- Reduced environmental impact

All of the gas turbine manufacturers are taking notice of these requirements.

2 gives the present range of of gas turbines offered by ABB, while **3** and **4** show the increase in availability of the ABB type 11N gas turbine and of some ABB combined cycle facilities with type 13E and 13E2 units.

Gas turbine core technologies and components

Advanced high-temperature gas turbines are characterized by an annular combustor configuration with dual burners and a compressor with rows of variable guide vanes. The following core technologies play a part in the dimensioning, design and production of all the key components of a modern gas turbine:

- Gas turbine and combined cycle process
- Aerodynamics and computational fluid dynamics (CFD)
- Complex heat transfer and cooling system design
- Clean combustion

- High-grade materials and protective coatings
- Mechanical integrity of the components
- Process management and control, C&I engineering
- Robust, production-oriented design, easy-to-maintain plant configuration, and proven auxiliary systems that are being constantly upgraded

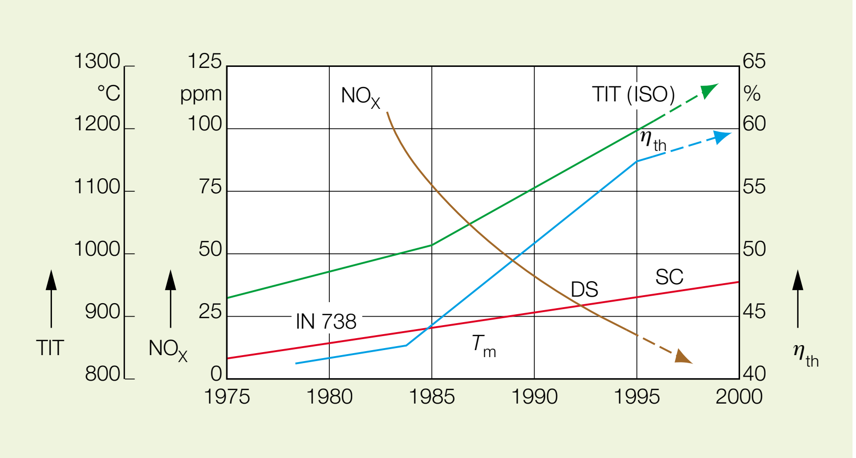
Quality has to be ensured during the design, production, assembly and commissioning phases through adherence to quality-oriented work processes within the framework of a design and production group. Gas turbine vendors have made exemplary progress in this area.

The design of the gas turbine is based on computer programs and design specifications which have been systematically developed and validated. Tests are performed on models as well as on original parts and components. In addition, the gas turbine prototypes have to be run on in-house test facilities or tested on-site, in either case requiring an enormous investment in measurement technology.

ABB recently built an advanced gas turbine test center at Birr in Switzerland for the purpose of testing the GT26 and other large gas turbines. The new center was necessary because of the difficulties experienced in carrying out comprehensive prototype tests in customers' works and because these tests were becoming increasingly complex and cost-intensive. Also, detailed tests often cannot be carried out on site for operational reasons.

The gas turbine process

The improvement in unit rating and efficiency is achieved via the gas turbine process and the relevant process data. Combined cycle operation is the starting point for the supply of base-load power in every case. In the traditional gas turbine process, the unit rating and efficiency is increased via the mass flow, the turbine inlet temperature and the corresponding pressure ratio.



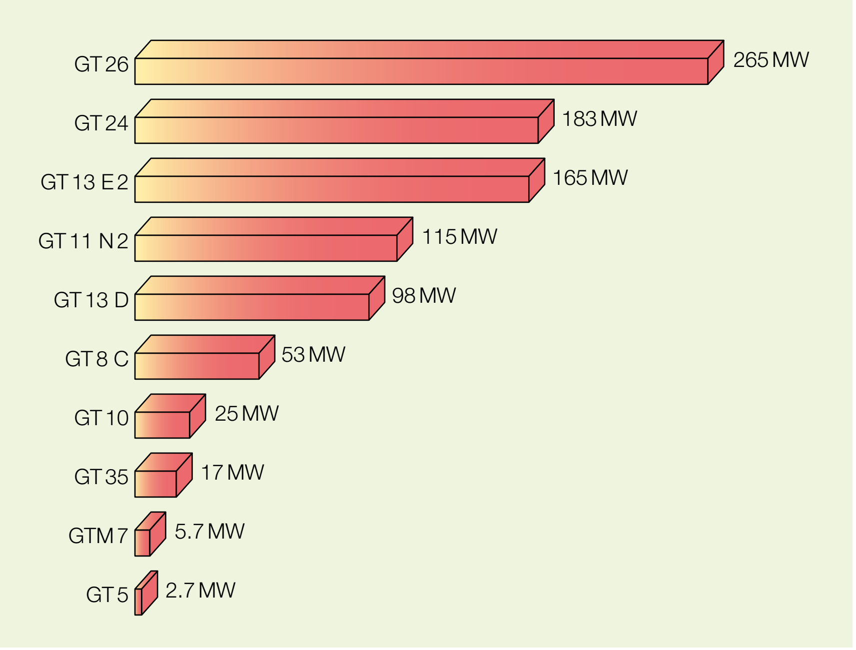
Development of combined cycle power plants in terms of the gas turbine inlet temperature (TIT), thermal efficiency (η_{th}), NO_x emissions (with natural gas) and permitted blade temperature (T_m) **1**

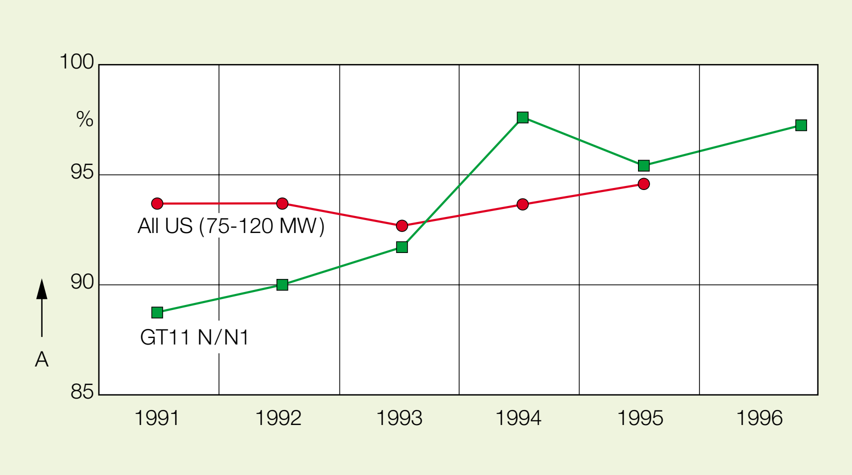
TIT (ISO) *Gas turbine inlet temperature*

IN 738 *Inconel 738, conventionally cast gas turbine blades*
DS *Direction solidified gas turbine blades*
SC *Single crystal technology*

1 illustrates in an impressive way how the turbine inlet temperature could be increased over the years in relation to the permitted material temperatures and thermal efficiency of the combined cycle plants. To obtain a thermal efficiency of 38 percent for the gas turbines and 58 percent for the combined cycle plant the firing temperature has to be increased dramatically and the components lying in the hot-gas path have to be appropriately cooled. The increase

Rated output of ABB gas turbines **2**





Comparison of the availability (A) of type GT11N/N1 gas turbines with machines of similar ratings in the USA **3**

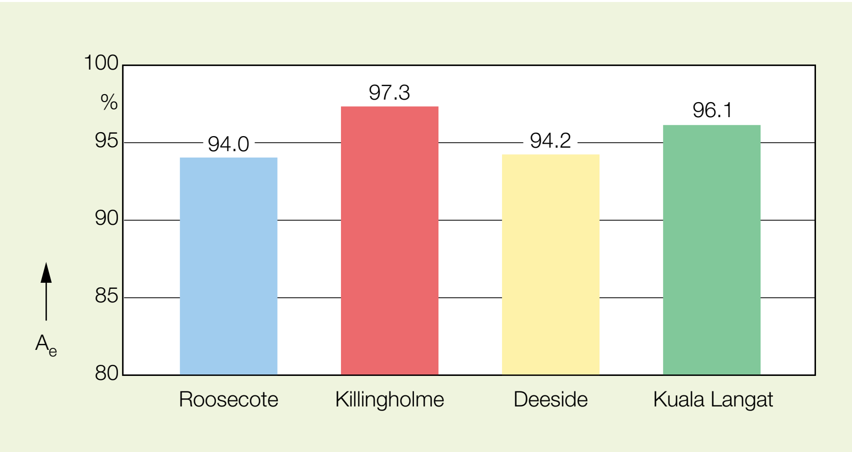
in cooling air, however, carries with it the risk of an increase in NO_x emissions, since the air-mass flow in the lean premix combustor decreases. Advances in aero-engine technology are applied in full here to the areas of cooling, materials and computer-based fluid dynamics.

The sequential combustion technology employed by ABB in the GT24 and GT26 gas turbines allows a thermal efficiency of 38 percent to be achieved, with the prospect of 40 percent in the near future without having to significantly increase the gas inlet temperature. This technology results in the following benefits:

- High specific power, and therefore a low air mass flow rate
- Low blade tip speed, resulting in low mechanical and thermal stresses
- Smaller size for the steam/water cycle plant
- Low gas inlet temperature, relatively low cooling-air consumption
- Low NO_x emission level, and no NO_x from the second sequential EV combustor
- High availability due to the use of proven components
- Low temperatures for the hot-gas path

5 gives the specific power and the thermal efficiency of today's ABB gas turbines as well as those of some other GT vendors [4 – 7]. To make a comparison of the 50 Hz and 60 Hz units easier, all the machine data have been reduced to 3,600 rev/min. The inlet air mass flow rate and the compressor pressure ratio of the different gas turbines are shown in **6**.

Equivalent availability (A_e) of some combined cycle power plants with type GT13E and GT13E2 gas turbines built recently by ABB. Roosecote, Killingholme and Deeside are in the UK; Kuala Langat is in Malaysia. **4**

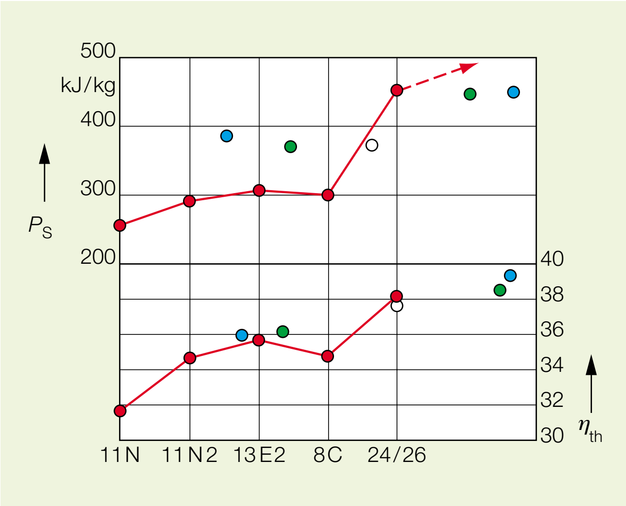


Compressor

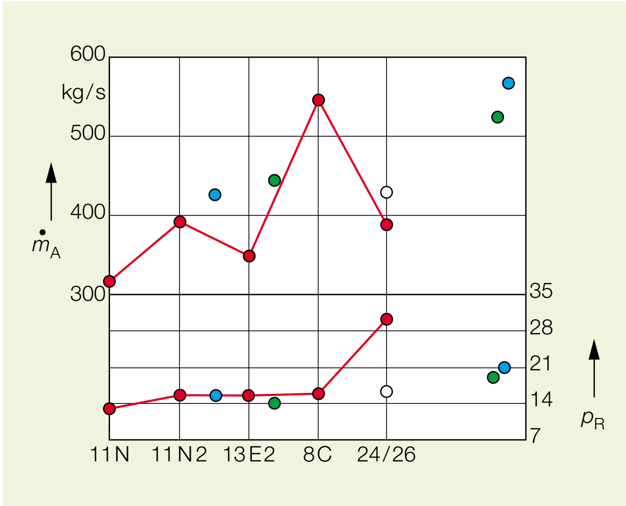
The working medium in a compressor flows counter to the increasing pressure, thus restricting the energy conversion in the compressor cascade. Because of this, and to avoid the flow separations that would otherwise occur, the compressor has to have a multistage configuration. Higher stage pressure ratios are among the top design priorities of engineers in their efforts to make compressors more compact, ie to make the unit lengths shorter and reduce the stage numbers. High mass flows and higher stage pressure ratios, however, require high peripheral speeds and flow velocities as well as a corresponding change in flow direction in the bladings.

The industrial compressors built for high pressure ratios (up to 150 bar) by the former BBC featured an axial/radial design with intercooler. In the meantime, ABB has continued developing its high-pressure compressor technology for gas turbine applications.

The transonic gas turbine compressor of the GT8 [8], introduced by BBC in the 1980s, still achieves outstanding values for mass flow and stage loading **6**. As early as 1983, a pressure ratio of 16 : 1 was achieved with the GT8 with only 12 stages. Today, the stage pressure ratios of the GT8 and the GT24/26 represent the highest values in the industrial gas turbine field. New type 7G and 501G2 machines developed by competi-



Specific power (P_S) and thermal efficiency (η_{th}) of GTs from ABB (red) and other vendors (blue, green, white) – all data reduced to 3,600 rev/min **5**



Inlet-air mass flow ($\dot{m}_A$) and compressor pressure ratio (p_R) of GTs from ABB (red) and other vendors (blue, green, white) – all data reduced to 3,600 rev/min **6**

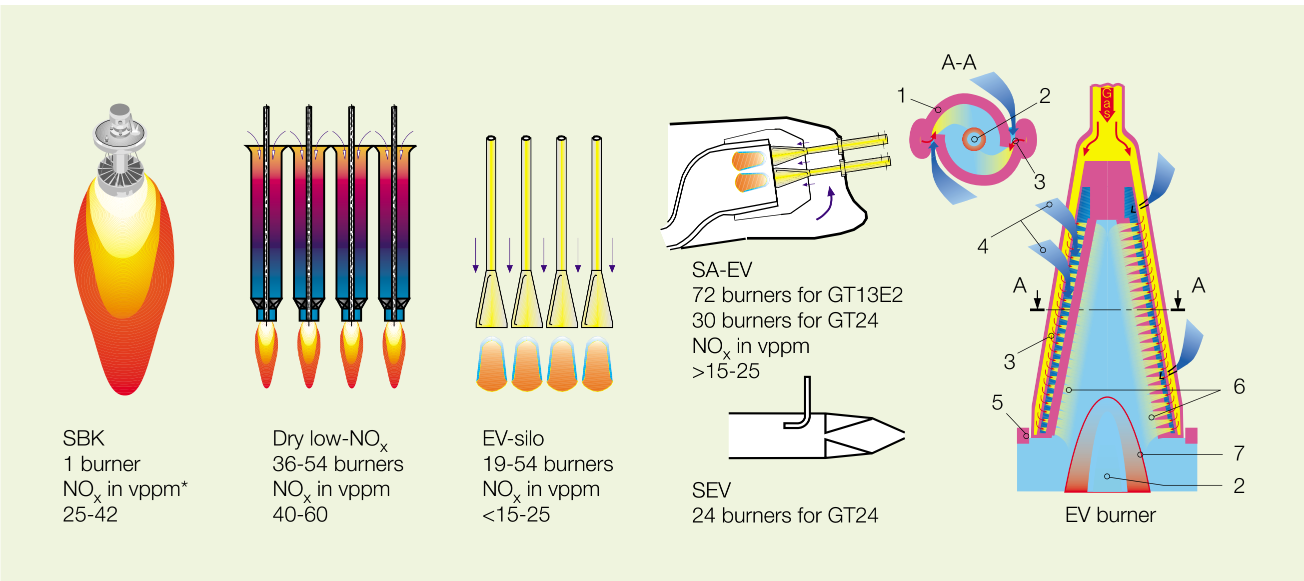
tors employ approximately the same technology as these.

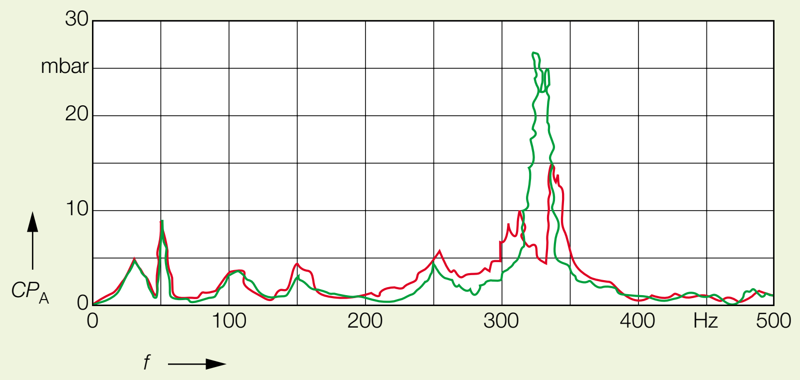
Development of the compressor profile has advanced steadily over the past 60 years, progressing from the 1st generation for AVA Göttingen through the 2nd and 3rd generations (NACA profiles) to the 4th and 5th generations with multiple circular arcs and controlled diffusion. An increasing amount of attention has been given to reducing the secondary losses in the peripheral zone and the tip clearance losses as well as to the relationship between the radial blade clearance and the surge margin. Additional

ABB burner technologies for natural gas and light oil (no 2) **7**

SBK *Standard burner*
* *With H_2O injection*
EV *Combustor for low-NO_x emissions*
SA *Annular combustor*
SEV *Sequential burners for low-pressure combustor*

1 *Vortex generator*
2 *Vortex core*
3 *Gas injection*
4 *Combustion air*
5 *Burner exit level*
6 *Mixing of gas and combustion air*
7 *Flame front*





Self-induced gas pulsations in combustors working under severe load conditions **8**

CP_A	*Gas pulsation amplitudes*	Green	*Without suppressors*
f	*Frequency*	Red	*With Helmholtz suppressors*

corrections to the blade profiles in the peripheral zones has also brought an improvement.

Combustion

The formation of nitrogen oxide in the flame can be reduced through measures that target, for example, a short residence time (multiple flames) or low flame temperature (lean premix combustion); other possibilities are substoichiometric staged combustion, catalytic combustion or the introduction of chemical measures.

The principle of lean premix combustion has been successfully introduced in industrial gas turbines. **7** shows the ABB burner technologies for natural gas and light (no 2) oil as well as the principle of operation of the ABB EV and SEV burners [9, 10, 11] and the burners used in the GT26.

The combustion of natural gas satisfies even the strictest emissions legislation. With a low-NO_x lean premix combustion system, neither water nor steam have to be injected to suppress the NO_x emissions. Other fuels besides natural gas can be burnt; often, diesel oil is used as the standby fuel in plants burning natural gas as the main fuel, and sometimes is even used as the main fuel itself.

Apart from NO_x, which is formed as a result of the high combustion temperature, this clean liquid fuel produces no hazardous emissions. Water or steam can be injected to suppress the NO_x emissions. Ongoing development of the EV burners at ABB aims at emission values which are lower than the permitted emissions for NO_x in 'dry mode', ie without water or steam injection.

The analytical methods that are used are based on calculation of the three-dimensional turbulent flow in the combustion chamber, with and without consideration taken of the reaction kinetics. The accuracy of this calculation depends to a large degree on the interaction between the burners and the combustion chamber, on the heat release, and on the turbulence models used. Appropriate test equipment and facilities are therefore as essential today as ever. Also, it is absolutely necessary for measurements and tests to be carried out on installed gas turbines, since the interaction of the burners and the combustion chamber is difficult to determine under laboratory conditions. A top priority of combustion chamber development work is the design of the air and fuel supply system. It is possible, in principle, for unacceptably strong pulsation of the gas volume to be self-induced in the combustion chambers under high load conditions. **8** shows the frequencies and amplitudes measured in the silo combustor of an ABB gas turbine without suppressors and also with some Helmholtz suppressors integrated into the design.

The sequential combustion principle that is employed in the GT24/26 **15** is based on ABB experience with this technology as well as on systematic development work and tests. The lean premix combustion that takes place in the SEV (Sequential EV) burner is self-igniting and produces virtually no NO_x emissions [11]:

The burner technology was further developed for medium BTU gas obtained from coal or residual oil gasification. At ABB, the EV burner was modified for dry combustion with low emission levels. In this process, a mixture of synthetic gas and nitrogen from an air separation unit is supplied to the burners [12]. Other vendors have adopted a different approach and mix steam with the fuel. Low BTU gas (blast furnace gas) can also be burnt in ABB gas turbines [3].

Turbine

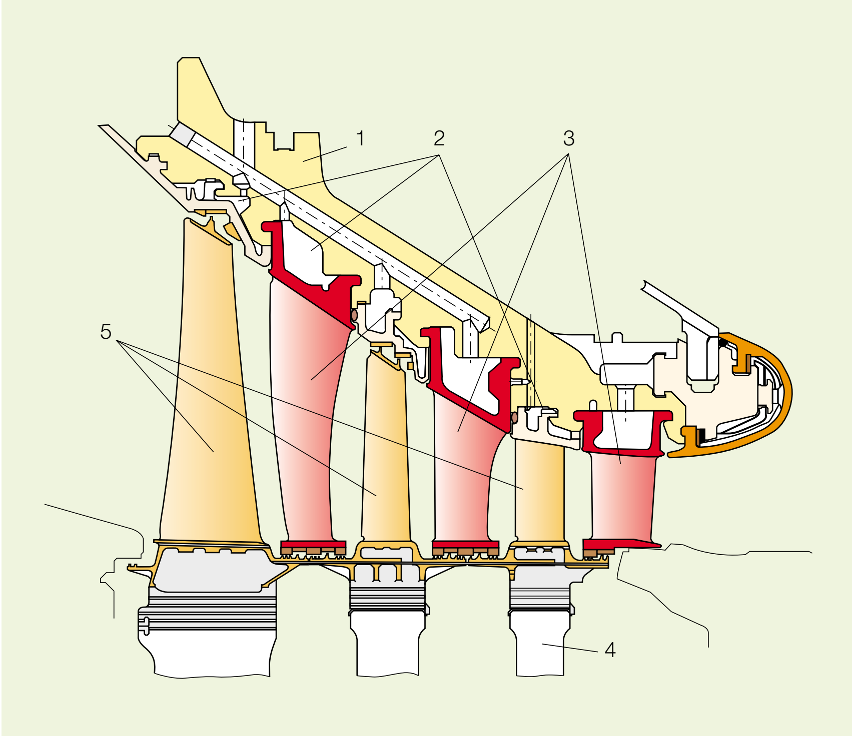
The three-dimensional flow calculations and the calculations used to design low-loss profiles for the turbine cascades are a key factor in modern gas turbine construction. **9** shows the blading of a type GT8 gas turbine. The shaping of the end contours, the radial clearance and the blade shrouds are all important aspects of the design process. Also, the heat transfer coefficients for the blade surfaces have to be determined with high accuracy in order to optimize the blade cooling.

A factor in the blade cooling is the minimum amount of cooling air that is required. Convective cooling with transverse fins, ribs on the inner walls, and impingement cooling (with minimum pressure loss) represent the state of the art for industrial gas turbines. At the beginning of the 1970s ABB became one of the first gas turbine vendors in the power plant business to introduce blade cooling. With film cooling, the efficiency of the film should be as high as possible. This efficiency depends on the conditions existing on the cooling-air side, on the outer flow conditions, on the arrangement and design of the holes, and on the exit angle of the cooling film, etc. Shower-head cooling is often used on the leading edge.

Gas turbine blades are subjected to huge centrifugal forces as well as gas-related bending forces. Thus, the creep rupture data of the blade materials are important design criteria. The blades have to be designed in such a way that the natural frequency of the blade will not coincide with multiples of the rotational frequency and the frequency of the periodic gas forces. To increase the mechanical damping, the blades are often linked by shrouds, with connecting bolts also used for the long turbine blades in the last row. Furthermore, cooled blades experience thermal stresses, which, although they decrease in time due to the creep effect, can lead to creep deformation and cause damage. The thermal stresses during transient operation, eg during start-up, shut-down and load changes, cause so-called low cycle fatigue (LCF) of the material. Cracks can occur if certain numbers of cycles are exceeded. In the case of high-temperature gas turbine blades working under high load conditions, such cracks can propagate, causing either a forced fracture or a high cycle fatigue (HCF) fracture as a result of forced oscillations.

Materials and protective coatings

The continued development of the turbine blade materials and improved casting processes have contributed in a big way to the substantial increase in turbine inlet temperature over the years. The conventional precision-cast blades made of IN738 were replaced in the first turbine



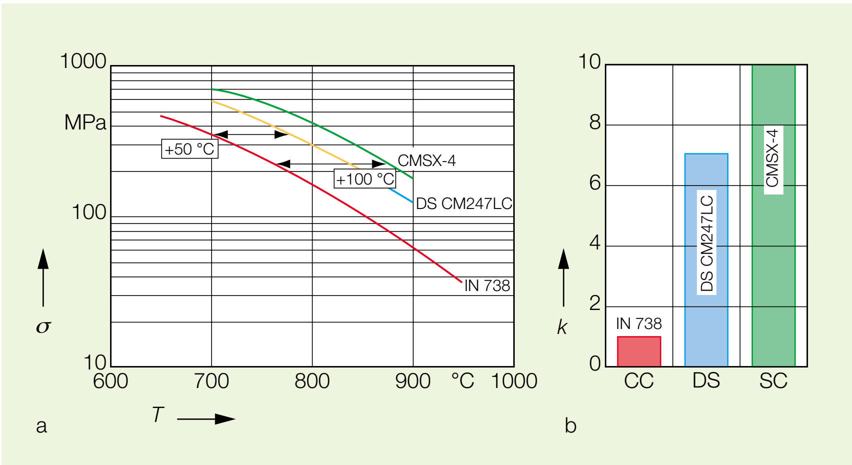
Blading of a type GT8 gas turbine **9**

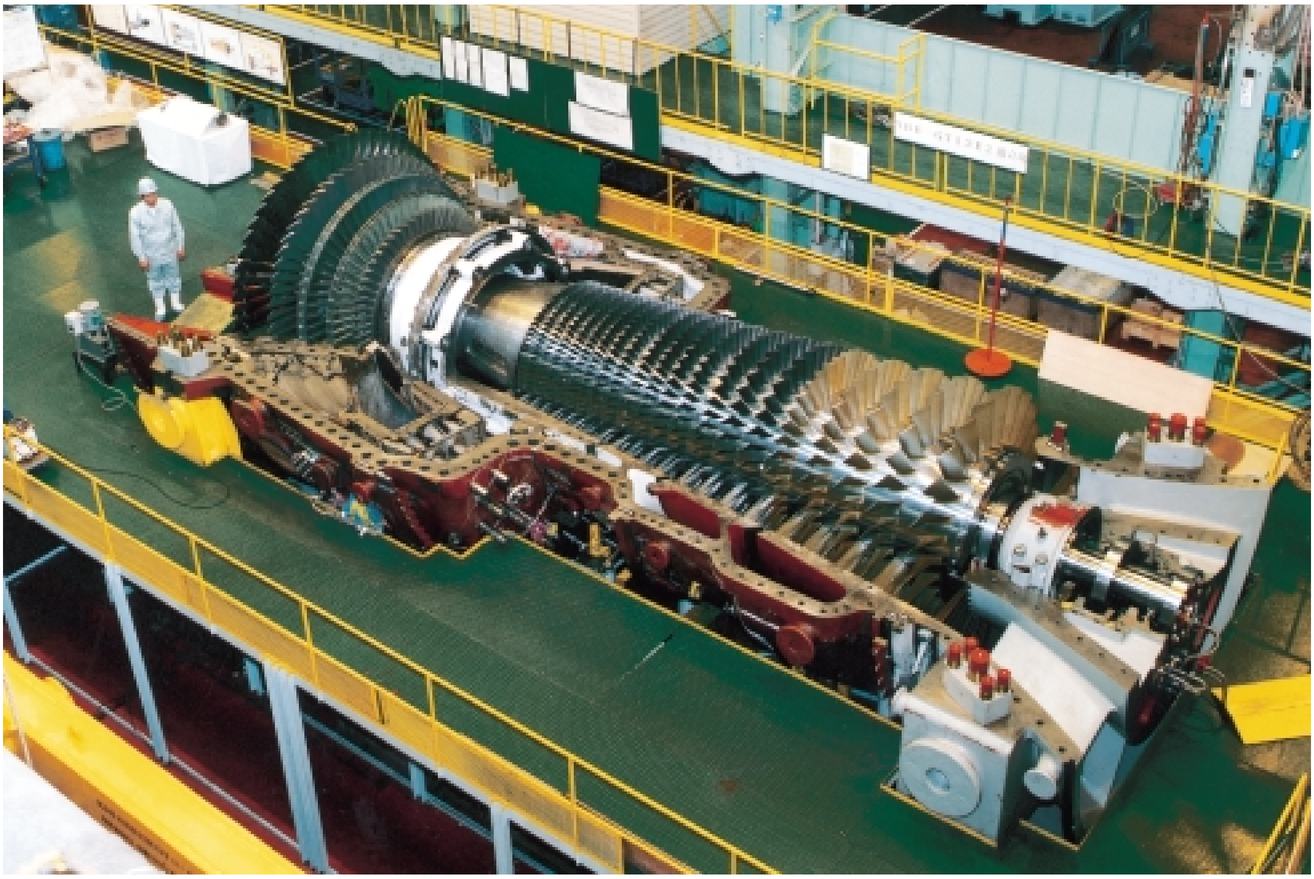
1 *Blade carrier*
2 *Cooling-air flow chambers*
3 *Guide vanes*
4 *Rotor*
5 *Rotor blades*

Improvement in long-time creep resistance (a) and relative improvement in cyclic load capability (b) of gas turbine blade materials, compared with Inconel 738 **10**

σ *Long-time creep resistance*
T *Temperature*
k *Improvement factor, compared with IN 738*

CC *Conventional polycrystalline blades*
DS *Direction solidified blades*
SC *Single crystal blades*





Type GT13E2 gas turbine being assembled in the Mannheim works of ABB **11**

stages by direction-solidified blades. Single-crystal, nickel alloy blades (CMSX2 and CMSX4) represent the latest development step in this area **1**.

An enormous improvement has been made in the long-time creep resistance and cyclic load capability as well as in the turbine inlet temperature, as **10** shows. Long-term experience with blades of this type is available from the aero-engine sector. In the industrial gas turbine field, only limited operational experience is available with modern DS and SC blades; the repair options, in particular, have to be determined on the basis of operational experience.

The development of coatings for protection against high-temperature corrosion and oxidation, and also of the so-called thermal barrier coatings, has allowed the cooling air flow rate to be reduced in spite of the higher hot-gas temperature.

Gas turbine design

Over the past 60 years ABB has built more than 1,200 gas turbines with a total rating exceeding 50,000 MW. Know-how based on decades of experience, good operational characteristics, a simple design, technological innovation and a focus on customers' requirements, underpin the ABB concept for gas turbines and combined cycle power plants. A report on the design features of the many different gas turbine types built by ABB over six decades appeared in [13, 14]. Between 1947 and 1960 BBC built dual-shaft gas turbines featuring an intermediate cooler, air preheater and dual heat supply (with reheat). The advantages of a single shaft were soon recognized and this design was consequently introduced. In spite of the wide range of designs based on this concept, the main components have remained the same. The design of today's large ABB gas turbines (with ratings exceeding 30 MW) is based on proven technology and characterized by simplicity and ease of maintenance. A welded shaft and two bearings plus a simple control concept are the fundamental characteristics of these turbines. The design of the smaller gas turbines, on the other hand, is traditionally based on aero-engine designs. Fundamentally, the design of ABB gas turbines has remained unchanged since the 1960s, although it has been continuously improved through further development in the years since.

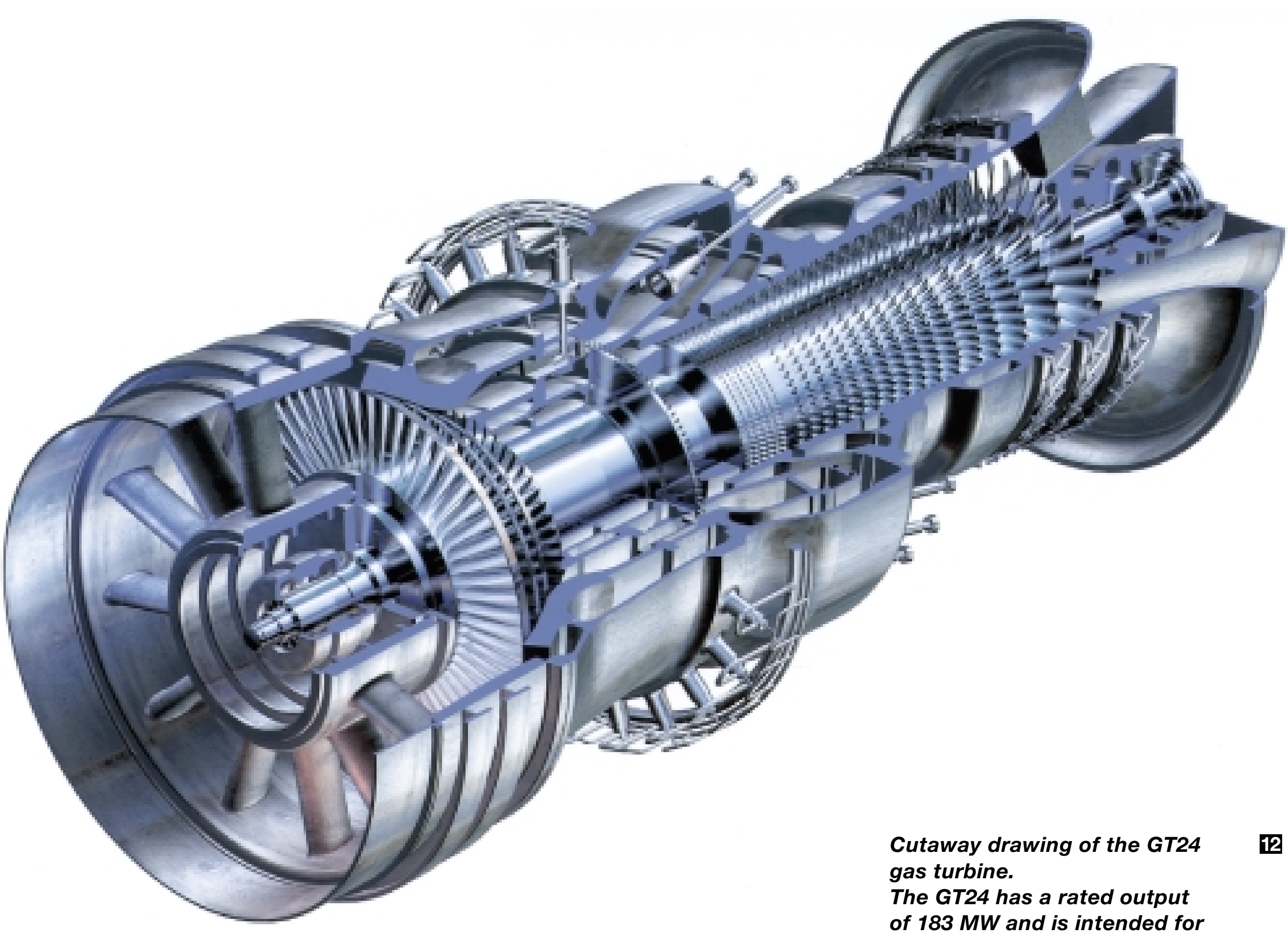
11 shows a GT13E2 during assembly. The GT13E2, which was derived from the GT13E1, has an annular combustor instead of a silo combustor to keep costs down and facilitate ease of maintenance as well as improve the hot-gas supply. The design of its combustor is based on the annular combustor of the GT8. Otherwise, the GT13E1 and GT13E2 are identical. The mass flows and the turbine inlet temperature of the GT13E2 have been increased slightly. The turbine inlet temperature could be raised without increasing the peak temperature due to the uniform temperature profile of the annular combustor.

One of the most important components of the gas turbine is the shaft. This is subjected to massive centrifugal forces at high temperatures. The rotor-cooling, which protects the rotor from the hot gas, and the slow, controlled warm-up during cold starting (to keep the thermal stresses low) are important rotor design criteria. Other suppliers use different designs for their rotors, based on their traditional design and production concepts. The comparison of the rotor designs of other vendors in [15] shows the main operational benefits of the welded construction, namely lower vibration and freedom from maintenance. The critical parts of the rotor are the first and the last turbine discs as well as the first and last discs of the compressor. The first compressor disc and the last turbine disc have to be able to withstand high centrifugal forces; the last compressor disc and the first turbine disc, on the other hand, are subjected to high temperatures. Field experience with the welded rotor shows it to be very robust with respect to both low cycle fatigue and reliability.

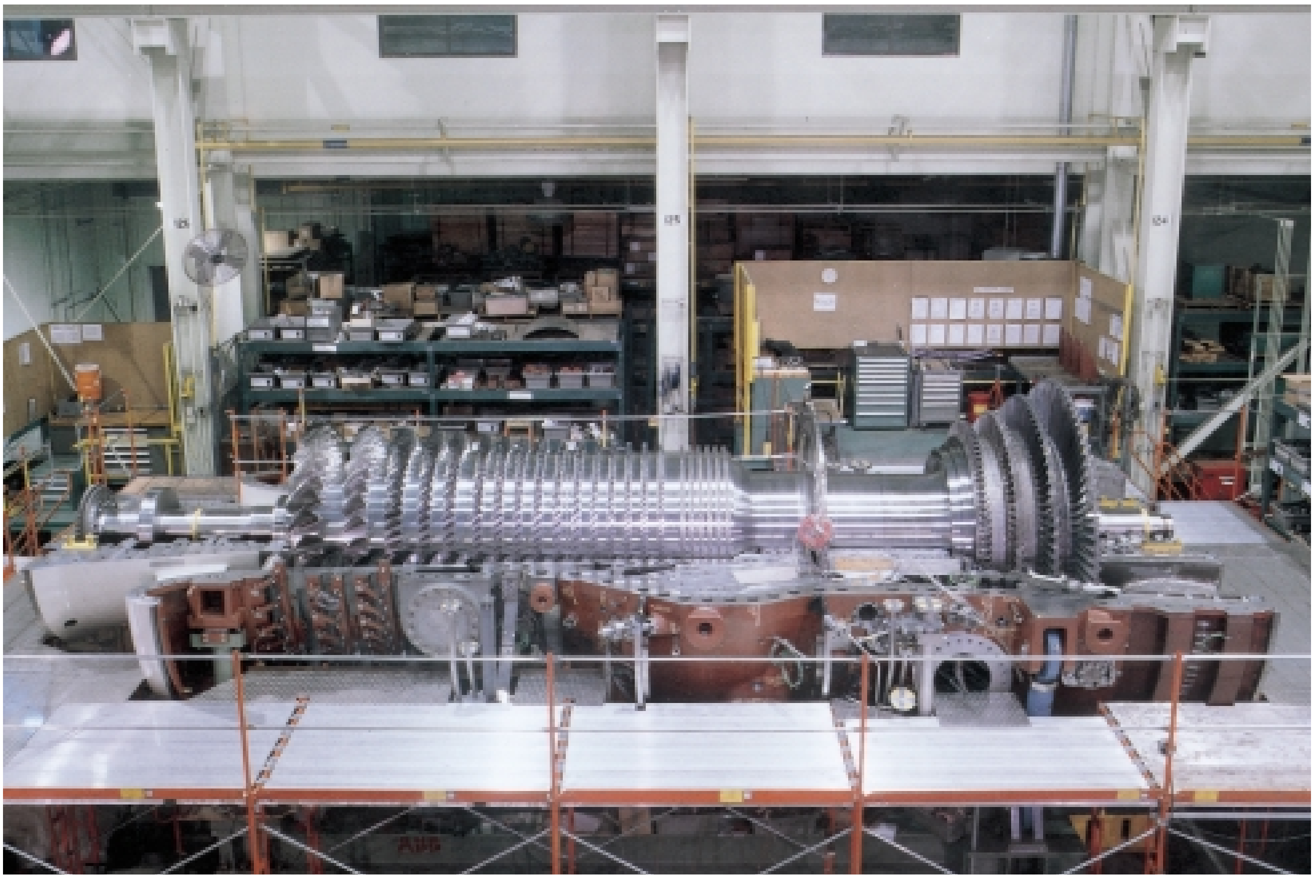
For gas turbines in the 30-MW class and above, the usual practice at ABB is to build up the shafts by welding forged discs together. Tests are carried out on the discs and the welded shaft to verify the mechanical properties and to identify possible faults. The compressor rotor blades are fixed in circumferential slots. So-called ‘fir-tree’ roots are used for the radial fixing of the turbine rotor blades, which are also secured axially. In the turbine zone, the shaft is fitted with heat shields to protect it from the high thermal loading caused by the hot gas. These shields are cooled by the compressor air, which is also used to cool the front rotor blades. The shaft lies in two bearings, access to which is easily gained without having to open the machine. The axial position of the rotor is fixed by a thrust bearing in the inlet casing.

Other manufacturers build rotors with discs held together by pretensioned bolts. Mutual slipping of the discs is prevented either by Hirth-type serrations or by the friction between the faces of the discs.

Modern high-temperature gas turbines increasingly are being employed with waste heat recovery boilers in combined cycle plants. Since the generator drive is



Cutaway drawing of the GT24 gas turbine. **12**
The GT24 has a rated output of 183 MW and is intended for 60-Hz networks.



Assembly of a type GT24 gas turbine in ABB's Richmond works, USA **13**

located on the cold side of the compressor, the entire turbine torque is transmitted via the compressor to the generator. When the torque is transmitted by friction via the discs, this has caused difficulties in the past. However, years of experience and further development work in this area have led to the bolted shaft also acquiring a reputation for being robust in operation.

Design features of the GT24/26

The GT24 (60 Hz) and the GT26 (50 Hz) both belong to the same gas turbine family. **12** shows a cutaway drawing of the GT24 and **13** a view of the same type during assembly. Almost all of the components of the GT26 are scaled-up (1.2 : 1) versions of the GT24 components. ABB employs tried and tested solutions here too: a welded shaft with two bearings and an annular combustor with EV burners. The sequential combustion system is based on 45 years of operating experience with a total of 27 units. 1978 saw the first single-shaft machine to be based on this concept built for the air-storage plant in Huntdorf, Germany.

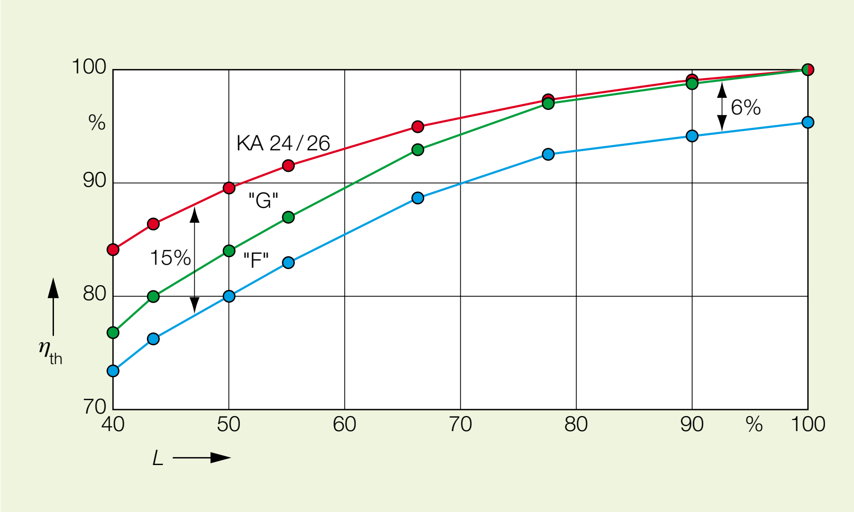
The inlet casing of the GT24/26 is of compact design and features an optimized inlet flow. Also, the bearings and the monitoring sensors can be removed without having to dismantle the casing. The compressor has 22 stages (pressure ratio 30 : 1) with three rows of adjustable guide vanes, resulting in relatively low stage loads and very good part-load behaviour **14**. **15** shows the main components of the middle section: the final compressor stage, the sequential combustion system with high-pressure turbine stage in the center, and the 4-stage low-pressure turbine on the exhaust-gas side.

The design of the compact high-pressure annular combustor is similar to that of the proven GT13E2. Both the inner and outer casings consist of simple, convection-cooled segments. The ends of the 30 EV burners, which are fixed to the hood, are located in the front segement. The fuel distribution systems for the natural gas and oil are integrated in the hood.

The low-pressure SEV combustor is of compact, annular design with segments which are cooled, as in the case of the high-pressure combustor, by convection. The diffusors in front of the 24 fuel injection lances are effusion-cooled.

The 3-D twisted turbine blades **15** are designed for use with a shroud joint. The rotor blades have axial fir-tree roots. Appropriate cooling of the high-pressure stage blades and of three stages of the low-pressure turbine ensure that the metal temperatures remain moderate. Boroscope openings allow easy inspection of the turbine.

The exhaust-gas casing and diffusor of the GT26 are aerodynamically optimized for maximum pressure recovery. Here, too, a proven design was used for the insulation of the supporting structure. Easy access has also been provided for inspection. The load on the bearings is relieved by means of spring supports.



Comparison of part-load characteristic of combined cycle power plants with GT24/26 gas turbines and combined cycle facilities from other vendors **14**

η_{th} *Relative thermal efficiency*
L *Load*

Red *GT24/26 gas turbines combined cycle plants KA24/26*
Blue *'F' class gas turbines from other vendors*
Green *'G' class gas turbines from other vendors*

Process control, monitoring, protection

The demands made on the gas turbine controller have grown rapidly in recent years. This is particularly true of the control precision during transient events, such as start-up, load reduction and frequency support. The new requirements are due to the operating range being more restricted, for example to allow higher efficiency and also stricter emission goals to be met. This restriction is defined in turn by temperature constraints, extinction limits, pulsation areas, surge limits, etc. Operation outside of the allowed range can lead to major damage, a massive reduction in the equivalent operating hours and a major reduction in the availability of the machine.

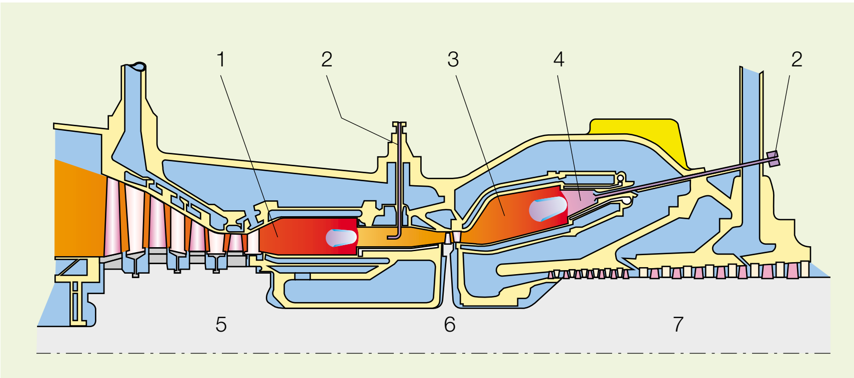
Sequential combustion offers considerably more flexibility. This potential has been fully utilized in the GT24/26 in the form of a new hierarchical control concept featuring an EV and an SEV burner fuel controller (for load change) and compressor guide-vane adjustment (for mass-flow change). The new concept was optimized by adapting it to the physical characteristics of the gas turbine process, which itself has an hierarchical structure. From the beginning, the development of the control concept was based on modelling, ie all the conceptual ideas were designed and tested with the help of a dynamic gas turbine simulator. This simulator is itself part of a state-of-the-art computer aided control system design (CACSD) environment developed for the design and optimization of highly complex controllers.

Another potential application area for the gas turbine simulator is on-line process monitoring. Changes can be determined from discrepancies between the process and the computer model, and the information used, for example, to help prepare maintenance concepts.

The protection concept relies on as much information about disturbance events as possible being received. Some of this information comes from a simu-

Main components of the middle section of the GT24 and GT26 gas turbines with sequential combustion system **15**

1 *SEV combustor*
2 *Fuel injection*
3 *EV combustor*
4 *EV burners*
5 *Low-pressure turbine*
6 *High-pressure turbine*
7 *Compressor*



lation of the operating conditions. While the protection measures serve operational reliability, they also generally impair the availability of the installation. The availability therefore has to be secured by introducing redundancy where necessary, by adopting automatic test procedures, and by the use of reliable, rugged components. The most important functions of the protection system are protective load shedding (load reduced to zero in 2 minutes) and the gas turbine trip. The latter should be avoided whenever possible due to the high stress it imposes on the machine.

Future prospects

Reflecting the current positive market trend, gas turbine development is progressing at a fast pace [4, 5, 16, 17]. An increase in the unit rating and thermal efficiency in parallel with acceptable emission levels and a rugged design will continue to be the main focal points. Sequential combustion and further development of the core technologies will enable ABB to achieve, in the near future, the goal of 60 percent thermal efficiency without compromising power plant availability.

All GT manufacturers are committed to further development of the key technologies. Steam cooling of the gas turbines in a closed loop which is integrated in the combined-cycle process, as patented by ABB already in 1982, has to be introduced with care. Problems involving deposits and blockage of the small cooling holes, start-up with cooling air, then changeover to steam, load change, shutdown, etc, have to be solved for large-scale commercially viable installations. Synergies can without doubt be found in certain areas (eg, materials, protective coatings and CFD) and full benefit should be taken of this potential through joint development work in international committees that include the gas turbine manufacturers. This should also have cost benefits for the manufacturers. Among the key technologies attracting interest are the combustion process and the combustor design, primarily as a result of the growing importance being given to fuel flexibility.

Sequential combustion, the high pressure ratio of the GT24/26 and the low and medium BTU burners in the GT11N2 and GT13E2, are future-oriented gas turbine technologies that show that ABB is on the right path.

References

[1] A. Meyer: The combustion gas turbine: its history, development and prospects. Brown Boveri Rev 26 (1939) 6, 127–140.

[2] A. Stodola: Load tests of a combustion gas-turbine built by Brown, Boveri & Company. Brown Boveri Rev 27 (1940) 4, 79–83.

[3] D. Mukherjee: Experience with unconventional gas turbine fuels. ABB Review 9/95, 29–37.

[4] R. Farmer: Steam-cooled 501G rated 230 MW with 2600°F rotor inlet temperature. Gas Turbine World, Nov/Dec 1994, 22–27.

[5] J. C. Corman, T. C. Paul: Power systems for the 21st century. 'H', Gas Turbine Combined Cycles, GER-3935.

[6] Siemens unveils 240 MW V94.3 gas turbine. Modern Power Systems – Staff Report. March 1995.

[7] H. Dörr: Die neue Generation der leistungsstarken Gasturbinen für den Einsatz in GuD/Kombi-Kraftwerken in Einwellenanordnung. BWK, vol 48 (1996) 1/2, 47–51.

[8] F. Farkas: The development of a multi-stage, heavy-duty transonic compressor for industrial gas turbines. ASME 86-GT-91.

[9] T. Sattelmayer et al: Second generation low-emission combustors for ABB gas turbines: burner development and tests at atmospheric pressure. Turbine and Aeroengine Congress and Exposition, Brussels, Belgium, June 11–14 1990, Paper no 90-GT-162.

[10] A. Aigner et al: Second generation low-emission combustors for ABB gas turbines: tests under full engine conditions. Gas Turbine and Aeroengine Congress and Exposition, Brussels, Belgium, June 11–14 1990, Paper no 90-GT-308.

[11] F. Joos et al: The SEV combustor: an innovative concept leading to single digit NO_x emission levels. PowerGen '95 Asia, Sept 27-29, Singapore.

[12] K. Döbbeling et al: Low NO_x premixed combustion of MBTU fuels using the ABB double-cone burner (EV burner). International Gas Turbine and Aeroengine Congress and Exposition, The Hague, Netherlands, June 13–16, 1994.

[13] W. Endres: 40 years of Brown Boveri gas turbines. Brown Boveri Rev 66 (1979) 2, 61–67.

[14] W. Endres: Gas turbine types 9, 11 and 13, development and performance. Brown Boveri Rev 64 (1977) 1, 5–11.

[15] W. Endres: Rotor design for large industrial gas turbines. International Gas Turbine and Aeroengine Congress and Exposition, Cologne, Germany, June 1–4, 1992.

[16] J. C. Corman: Gas turbine power generation – status and environmental considerations. ASME 95-CTP-29.

[17] H. Matsuzaki et al: Development of advanced gas turbines. ASME IGTI Conference, Birmingham, 1996.

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