World's highest capacity steam turbosets for the lignite-fired Lippendorf power station

The two 933-MW steam turbosets being supplied by ABB to the Lippendorf power plant in Germany are the highest capacity, most efficient high-temperature, single-shaft units ever to be built for a fossil-fired power station. At full load, the power plant units will operate with a net efficiency of 42.4 percent. This high efficiency is made possible by new high-temperature technology that is being used for the first time in the Lippendorf plant. Key turbine components are made of improved, heat-resistant steels designed to withstand the supercritical steam conditions. The first unit is due to go on line in October 1999.

The lignite-fired Lippendorf power plant with the two units 'R' and 'S' is being built south of Leipzig as the third new power station to be operated by VEAG Vereinigte Energiewerke AG, Berlin, which is owned by a group of German utility companies. When completed it will be one of the most technologically advanced and economical coal-fired power plants anywhere. The high-temperature process for which the two units have been developed allow supercritical steam conditions and higher efficiencies that will set new standards for lignite-based power generation.

The power capacity of 933 MW per unit and net efficiency for the plant of 42.4 percent make it one of the world's most efficient and largest power plants to be fired with brown coal.

The significant increase in efficiency was made possible by the development of the high-temperature process, in which ABB has played a dominant role and which is used for the first time at Lippendorf. The high-temperature process is a logical and inevitable development step in power plant technology as vendors and utilities search for ways to achieve higher efficiencies. Studies carried out to determine the most economical process parameters showed that increasing the live-steam and reheat-steam temperatures as well as the live-steam pressure and the final preheater temperature gave the best results.

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As part of the joint European COST programme, which was initiated to further the development of heat-resistant steels, steels with ferrite-martensite structures were studied to determine their suitability for use in modern power generation facilities employing high-temperature technology. It was found that a modified 10-percent chromium steel offered a temperature gain better than 30 °C for the same fatigue strength and lifetime as the materials currently in use.

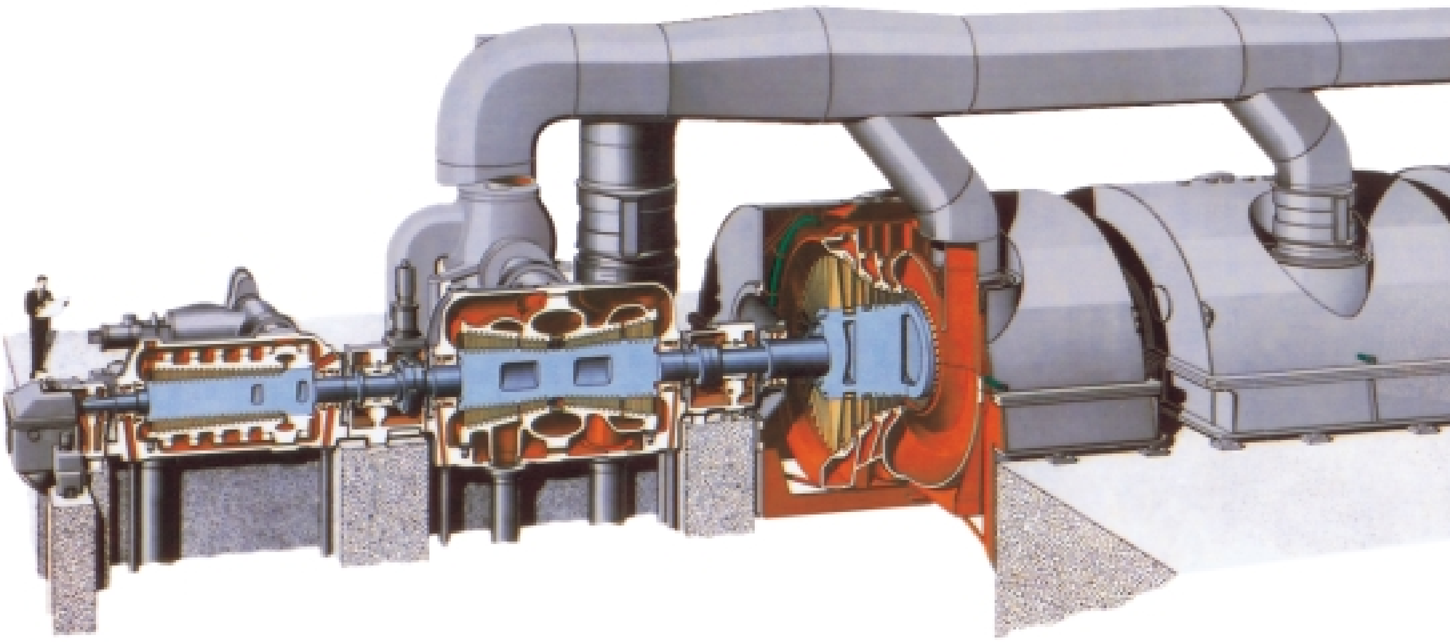
Use of the new steel considerably increases the high-temperature strength of those components of the Lippendorf steam turbines that have to withstand the full impact of the new steam data, ie the forged shafts of the HP and IP turbines, the cast valve and turbine casings, and the steam ducts.

Turboset

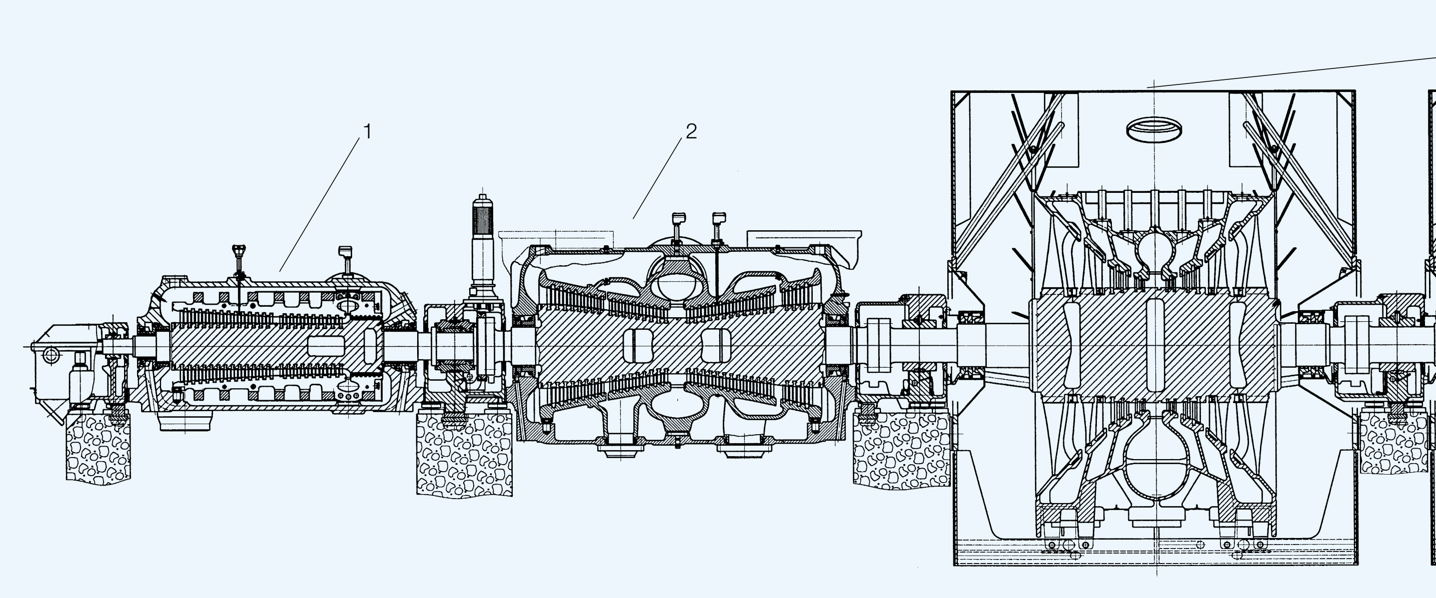
The heart of each of the lignite-fired units is a 933-MW steam turboset, built and installed by ABB Kraftwerke AG of Mannheim working together with ABB Kraftwerke Berlin GmbH. Both of the steam turbosets, which are currently the world's most powerful single-shaft units to be used in fossil-fired power plants, are from ABB's new modular series of reheat turbines for outputs of between 100 and 1,200 MW **1** (*Table 1*).

This range of turbines was developed specifically to meet demands for high output, operational flexibility, high availability, low heat consumption and short delivery times. Designed originally for conventional data (565 °C/565 °C/250 bar) and for outputs of up to 1,200 MW, the turbines are already operating in many plants. As a result of the use of the new materials, they are now also available for application in the high-temperature range of 600 °C/600 °C/300 bar.

By using 10-percent chromium steel for the key components it is possible to employ the new turbine series for the high-temperature process without re-



***933-MW steam turboset for new units R and S of the Lippendorf lignite-fuelled power plant. The turbosets are the most powerful high-
in the world.***



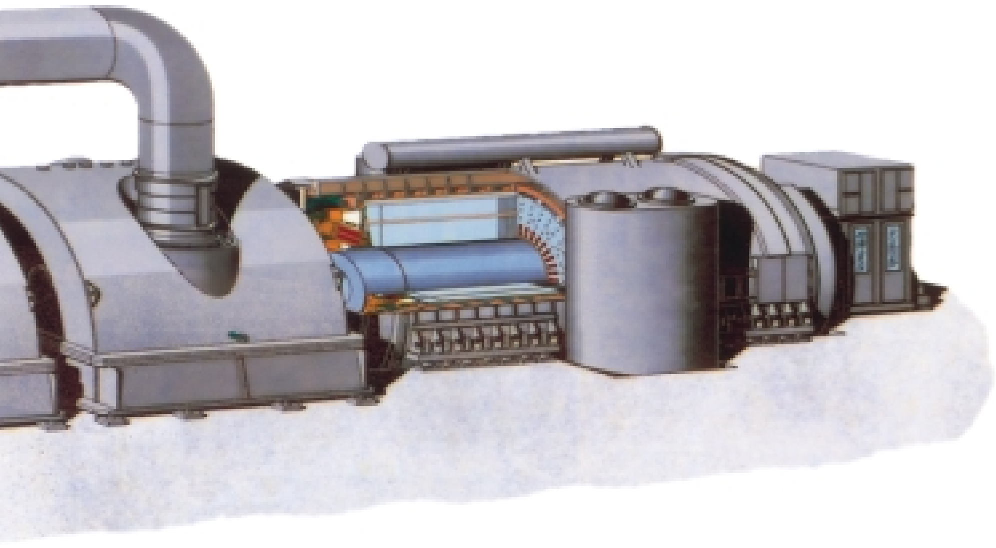
Longitudinal section through one of the steam turbines for the Lippendorf power plant

1 *High-pressure turbine*
2 *Intermediate-pressure turbine*
3 *Low-pressure turbines*

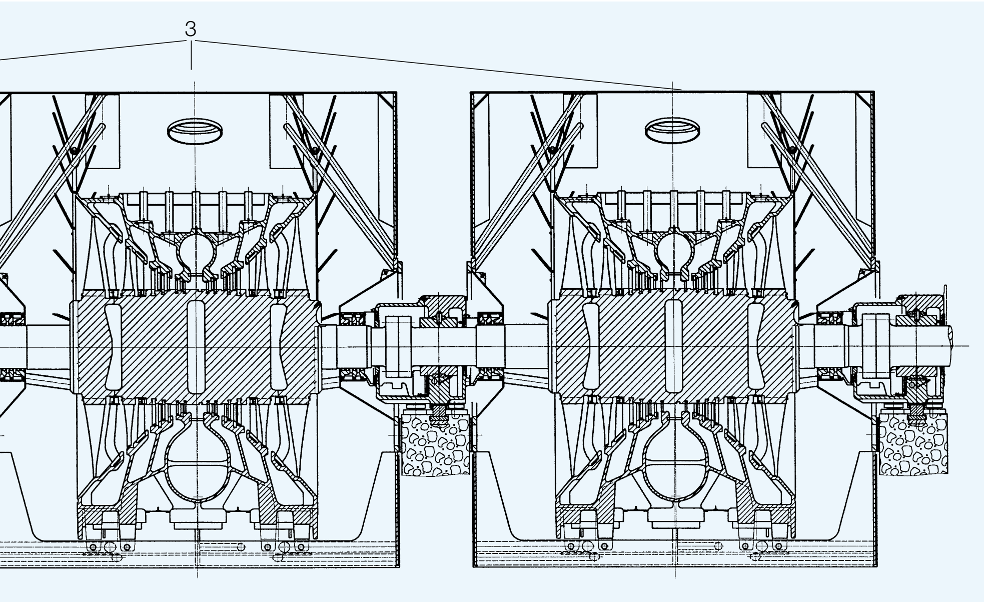
striction and without the need for additional, time-consuming development work, with the extra disadvantage of less operational experience being available. Design principles used in ABB steam turbines which have proved their worth over many years are retained. The only parts of the freely expanding double shell of the HP and IP turbine casing to be cast in the new 10-percent chromium steel are the inner casings and the live-steam and intercept valve chests flange-mounted directly onto the HP and IP outer casing.

The live steam is directed to the turbine inner casing via an inlet valve diffuser integrated in the valve chest, so the turbine outer casing is not subjected to the high steam temperature.

ABB's proven shrink-ring design for the HP inner casing is easily able to cope with the increase in live-steam pressure



temperature, single-shaft machines for fossil-fired power stations anywhere 1



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to over 250 bar. This design allows adjustment to higher steam pressures through the addition of another shrink ring or minor widening of the shrink rings. Neither of these measures adversely affects the thermal flexibility of the turbine during start-up.

Since ABB turbine rotors consist of solid, forged discs welded together to form a compact shaft, the new 10-percent chromium steel only needs to be used for the hottest parts of the rotor in the steam inlet zone of the HP and IP turbines.

The continuing development of tried and tested components and the feedback of operational experience has led to new optimized designs. These include the inlet scrolls and the radial-axial first-stage blading in all the turbine sections, pre-tensioned rotor blades and new blade profiles, designed and optimized using the latest 3D CAD techniques.

The turboset consists of a single-flow HP turbine, a double-flow IP turbine and three double-flow LP turbines 2. The shaft system is supported between the turbines and the generator by a single bearing. The rotors of the turbine sections and the generator are rigidly linked by means of integral expansion sleeve couplings. Axially arranged labyrinth seals with spring-backed ring segments prevent the steam from escaping at the gaps between the rotor shaft ends and the casing.

The live steam flows from the steam generator through the steam supply lines to the live-steam main stop and control valves flanged onto the HP outer casing. The steam passes via the extended diffuser of the control valves to two 180° inlet scrolls integrated in the HP inner casing, and from there via the radial-axial first-stage blading into the reaction blading of the HP turbine 3. After expanding, the steam flows through the exhaust-steam section of the HP outer casing to the two exhaust nozzles.

From the nozzles, the steam passes to the reheaters and on to the combined main stop and intercept valves of the IP turbine. The steam supply from the valve casings to the IP inner casing is in each case via flanged, freely expanding steam ducts 4. The superheated steam flows through two 180° inlet scrolls integrated in the IP inner casing into the radial-axial first-stage blading and into the double-flow reaction blading, where it expands to the IP exhaust steam pressure. Finally, it flows via two exhaust-steam nozzles on the top half of the IP outer casing and the crossover pipes to the three LP turbines.

Table 1:
Main technical data of the steam turbines

Generator terminal rating	933	MW
Live-steam flow rate	672.2	kg/s
Live-steam pressure	259.5	bar
Live-steam temperature	550	°C
Steam flow rate after reheat	596.8	kg/s
Steam pressure after reheat	49.8	bar
Temperature after reheat	582	°C
Condenser pressure	0.038	bar

A vertically arranged steam duct directs the steam into the 360° inlet scrolls integrated in the LP inner casing. The steam flows through the radial-axial blading and the two flows of the conical, smoothly shaped steam path to the annular diffuser, after which it flows down through the exhaust-steam section of the LP outer casing to the condenser.

The fixed point for the turbine on the foundation is the bearing pedestal between the IP and the first LP turbine section. Temperature rise causes the IP and HP turbine as well as the thrust bearing pedestal, which is wedge-coupled, to expand together as a single, interconnected system in the direction of the front bearing pedestal. The front HP outer casing brackets slide on the front-end pedestal, which is fixed. The sides of the LP turbine sections are fixed individually by means of baseplates anchored on the foundation.

The fixed point for the shaft system of the turboset is the thrust bearing in the thrust bearing pedestal between the HP and IP turbines. The HP rotor expands away from the thrust bearing in the direction of the front journal bearing and main oil pump drive. The IP and LP rotors expand in the direction of the generator. This arrangement ensures minimum axial movement between the stationary and moving blades. Vertical keyways between the HP and IP turbines and the bearing pedestals and the turbine foundations, as well as between the LP turbines and their foundations, ensure that the turbine is properly centered.

Rebalancing of the turbine rotors can be carried out on all of the turbine sections. The first and last rows of blading as well as the blade rows at the extraction points can be inspected by means of boroscopes, so there is no need to dismantle the outer and inner casing.

Highest efficiency with 3D-optimized blading

The part of the turbine playing the most important role in efficiency and fuel utilization is the blading. ABB has developed new, complex calculation software and flexible production technologies that allow further optimization of the blading. The blade form 8000, with a strongly curved camber line, wedge-shaped and pointed leading edge and long, straight back profile, has been used with great success in a large number of installations for more than 15 years and can hardly be improved on even with the help of the most advanced software.

Further development has therefore concentrated on reducing the secondary flow losses through optimization of the lean and twist, and on reducing the leakage losses at the blade tips by modifying the degree of reaction over the blade height.

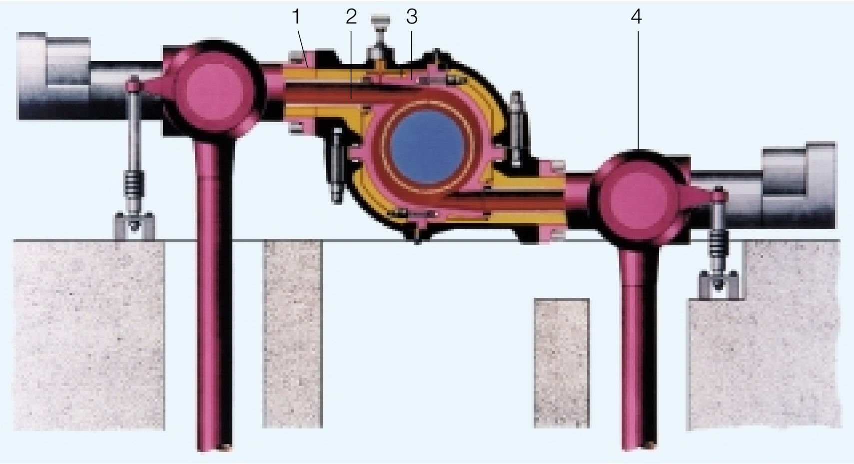
The computed effect of the changed blade geometry parameters was verified using test blading prior to installation of the blades in large steam turbines.

The calculated blade geometry data are transferred as data sets to the production cells in which the 3D-contoured, high-performance blading is manufactured. No drawings are needed.

The large potential for improvement in the LP turbines, in particular, could be exploited by means of coordinated and simultaneous optimization of the three-dimensional flow in the blade channel and in the following LP exhaust-steam zone.

High-pressure turbine: cross-section **3**

1 *Flanged joint, designed for HP exhaust steam*
2 *Diffuser steam duct (material: X 8 CrNiMoVNb 16 13)*
3 *HP inner casing (material: G-X 12 CrMoWNiVNbN 10 11)*
4 *Live-steam valve casing (material: G-X 12 CrMoWNiVNbN 10 11)*



The last-stage stationary blade design, ie the ‘lean’ and ‘sweep’ ensures a low-loss hub flow even at part load; this avoids the need for exhaust baffle plates, which have an adverse effect on the general availability.

A collar cast onto the lower part of the LP inner casing **5** smooths the exiting steam flow and prevents new vortices from being formed, thereby reducing the pressure losses in the condenser neck.

All of the blades for the HP and IP turbines and the moving blades for the LP turbines are produced from solid bars. With the exception of the forged LP last-stage blades, they are milled together with the root and shroud to form an integral unit. This method of ‘joining’ the blade parts is superior to every other.

As blade material, ABB uses austenitic steel in the temperature range above about 540 °C and steel with a martensite-ferrite structure and a chromium content of 12 percent in the temperature range below about 540 °C. These materials have been used for three decades with great success. Over the years, their properties have been continually improved and optimized by ABB in close collaboration with the material suppliers.

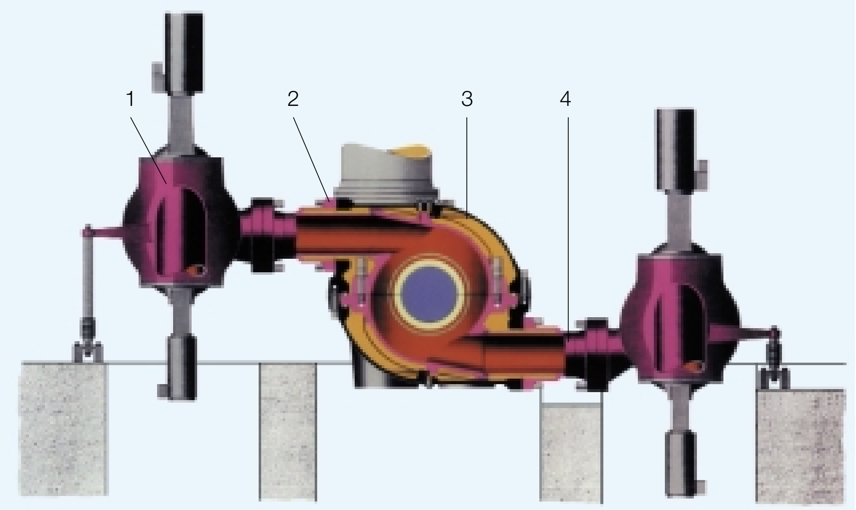
Generator system

The generator system for each unit comprises a generator from the 50WT25E-158 range, the static excitation equipment, and the ancillaries for the hydrogen cooling, seal oil and stator cooling-water system.

Turbogenerator

The generator, which features proven ABB MICADUR insulation, has been designed to temperature class F, but will only be operated by the owner in the class B temperature range **6** (*Table 2*).

Design features of the generator, which was developed together with the customer, include direct hydrogen-cooling of the rotor winding and stator core



Intermediate-pressure turbine: cross-section **4**

1 *IP intercept valve casing (material: G-X 12 CrMoWNiVNbN 10 11)*
2 *Flanged joint, IP exhaust-steam conditions*
3 *IP inner casing (material: G-X 12 CrMoWNiVNbN 10 11)*
4 *Steam duct (material: G-X 12 CrMoWNiVNbN 10 11)*

Nodular cast iron parts of the LP turbine inner casing after machining of the flanges **5**

Table 2:
Main technical data of the generator

Rated apparent power	1,167	MVA
Rated active power	933.6	MW
Power factor, overexcited	0.8	
Rated voltage	27	kV
Rated frequency	50	Hz
Rated current	27,954	A
Rated exciter current	6,001	A
Short-circuit ratio	0.505	
Total weight	588	t
Weight of rotor	97	t
Shipping weight of stator	410	t

and direct water-cooling of the stator winding. The output and efficiency of the generator were optimized by giving special attention to the dimensioning and selecting proven technical products and materials.

Stator casing

The stator casing is basically a single-section, welded steel cylinder, braced for extra strength. On either side of the gas-tight, pressure-resistant structure are flange-mounted cooler pockets for the hydrogen coolers, which are suspended in pairs inside them.

The inside of the generator, which is filled with gas under pressure, is sealed where the shaft passes through the ends of the casing by a ring. This ring is fixed circumferentially but is movable in the radial direction, and surrounds the shaft with only a small clearance. The remaining gap between the shaft and ring is sealed by oil, fed at high pressure by a separate sealing oil supply system. This ensures reliable sealing of the generator casing when the machine is in operation and when it is at standstill. The pressure of the seal oil is approximately 0.5 bar above the hydrogen pressure. At less than 9 m^3 per 24 hours, the hydrogen gas consumption lies considerably lower than the 12 m^3 recommended by the VDEW.

Stator core

The rotating magnetic flux in the air gap excites oscillations at double the power system frequency in the core. In the case of two-pole machines, the result is a 4-node oscillation. Because of this, the back of the core of machines in this power class is guided inside aluminium stator wedges, which are connected to wedge carriers welded to the casing. Such an arrangement ensures that core oscillations cannot be transmitted to the casing. The wedges and wedge carriers are joined at both ends of the core by end rings to create an electrically conducting cage that completely surrounds the core and directs the currents induced by the stray field along defined paths.

Fully insulated tension bolts are used to apply axial pressure to the low-loss compression plates, which consist of magnetic sheet steel laminations glued together. The core and the compression plates are cooled by the hydrogen gas flowing to the center of the generator through axial channels in the core tooth and yoke area.

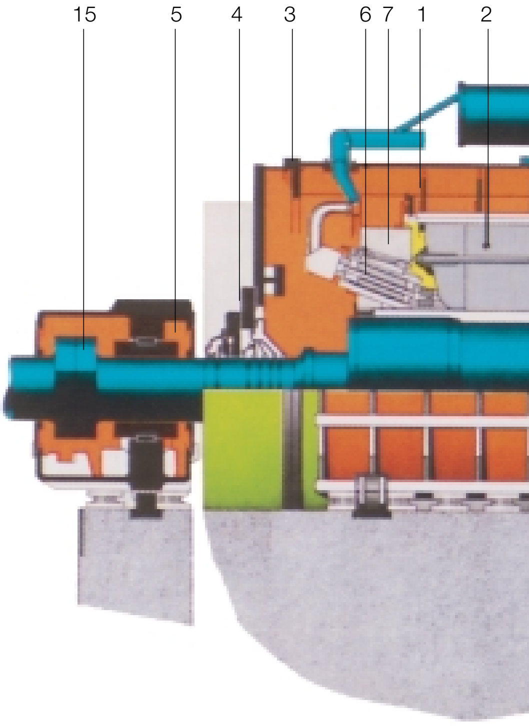
The core, approximately 7.9 m long and weighing about 290 t, consists of segments of low-loss, silicon-alloyed magnetic sheet steel, each side of which is coated with a layer of heat-resistant varnish. During stacking of the laminations in the casing, the core is compressed at regular intervals and finally sealed through the simultaneous application of vibration, heat and pressure. Loosening of the laminations during operation is therefore impossible.

Stator winding

The reliability of the stator winding system, comprising the bar configuration, the cooling and insulation system, the slot wedging and the winding overhang support, plays an important role in the overall availability of the generator. The stator winding bars comprise copper strands and the hollow steel conductors through which the cooling water flows. The copper strands and the steel conductors are transposed over their entire length.

Longitudinal section through a turbogenerator of

1 *Stator casing*
2 *Core with compression plates*
3 *Casing end*
4 *Gland casing*
5 *Bearing*



The double Roebel bars of the stator winding are insulated with epoxy resin impregnated fiberglass. The insulation is made by impregnating the wound bars with a solvent-free, environmentally compatible epoxy resin under vacuum, followed by curing at high temperature in moulds. Afterwards, a coating of corona-protection varnish is applied to the surface of the bars. This insulation system, known as MICADUR, meets all the requirements of temperature class F.

After the bars have been mounted, the winding is wedged into place using convex-concave wedges. These ensure a permanent wedging force which is greater than the electromagnetic slot forces occurring in operation, thereby preventing loosening or vibration of the bars.

Copper loops connect the ends of the bars to each other and to the winding connections. The cooling water enters and exits the bars through water boxes at their ends, the boxes being connected by hoses to the manifolds. Copper pipes cooled directly by water are used for the winding connections.

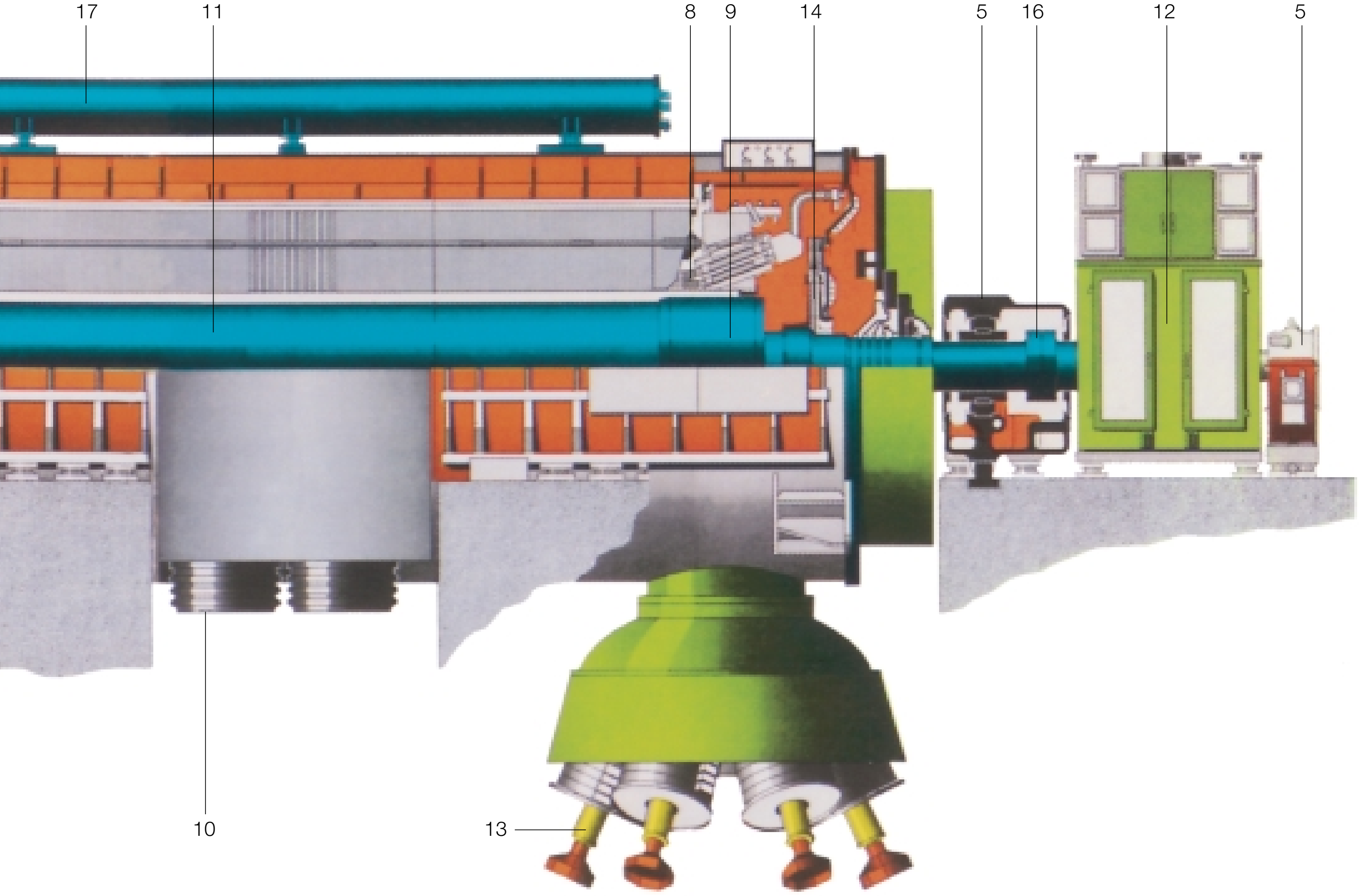
The winding overhangs are held on the inside and outside by two solid, fiberglass-reinforced epoxy resin rings – one external and one internal – in an arrangement that allows retightening. A clamping device ensures a defined pretension for the entire winding overhang which can be checked during overhauls and adjusted as necessary. The suspension of the overhang windings also allows thermal expansion in the axial direction, making the generator suitable for load-change and start-stop operation.

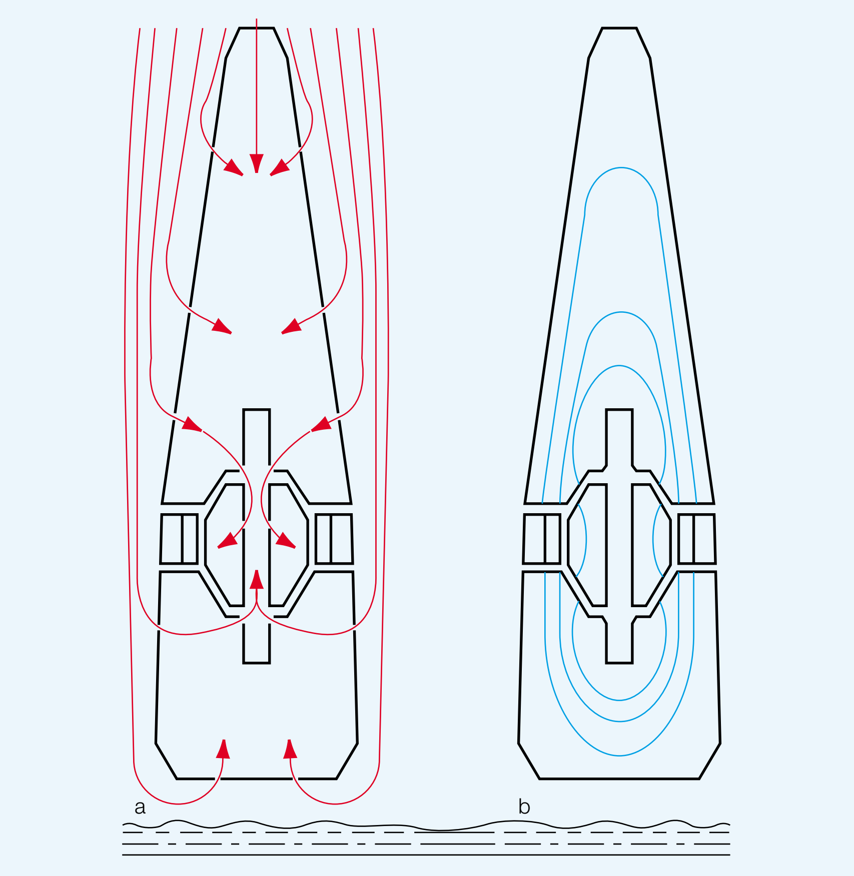
The electrodynamic forces acting on the end turns in operation and during disturbances are absorbed by the so-called winding overhang support. This has the task of holding the entire winding system in position to prevent damage being caused by inadmissibly high vibration amplitudes.

the type installed in Lippendorf power plant

6

6 *Stator winding overhang*
7 *Stator winding overhang support*
8 *Stator winding*
9 *Retaining ring*
10 *Hydrogen-gas cooler*
11 *Rotor body*
12 *Brushgear*
13 *Ducts*
14 *Blower*
15 *Coupling, to turbine*
16 *Coupling, to slipring shaft*
17 *Water tank*





Flow distribution around a bundle of the CM condenser (a) and the isobar pattern inside the bundle (b) **7**

Rotor body

The rotor body is an integral forging made of heat-treated steel alloy with a high magnetic permeability. The slots for the rotor winding are milled along the full length of the rotor body. So-called flexure grooves (cross-cuts) in the pole regions ensure uniform flexibility in all the rotor cross-sectional axes.

Copper bars are used for the field current infeed. These lie inside a central bore on the non-driven side as well as in radial bores below the rotor overhang winding.

Field winding and damper winding

Direct, axial hydrogen cooling is used for the generator rotor winding. The advantage of axial cooling is that the field winding conductors exhibit the same temperature level in every slot cross-section, so there is no relative movement between the hollow conductors. Orifices in the air-gap region enable the blower pressure to be utilized as additional pressure for the rotor on the driven and non-driven sides.

The field winding consists of concentric coils of silver-alloyed copper hollow conductors, made up of semi-turns soldered together in the overhang winding. It is stopped from being pulled by the centrifugal forces by the wedges that form the damper winding and by the rotor retaining rings. Fiberglass blocks are used as coil spacers in the overhang winding region. Hydrogen gas flowing through the hollow conductors cools the winding direct. The heated gas exits the hollow conductors in the core-and-winding assembly at four axial locations, from where it flows through radial grooves in the core to the hydrogen cooler. A small portion of the hydrogen gas exits in the center of the overhang winding and passes into the air gap through grooves in the pole region close to the rotor retaining rings.

The damper winding consists of slot wedges extending over the full length of the rotor, the damper segments and the rotor retaining rings. Additional damper slots with wedges of the same shape are located in the pole area. These make contact at the end of the core-and-winding assembly with the fingers of the damper segments, which are in electrical contact with the rotor retaining rings. Compression of the contacts is ensured by the action of the centrifugal force.

The rotor retaining rings, which are made of non-magnetic, austenitic steel which is resistant to stress corrosion cracking, are shrunk-mounted and secured against axial displacement by a bayonet lock and against tangential displacement by wedges.

Turbine condenser

For the condensation of the exhaust steam of the 933-MW steam turbosets, ABB Kraftwerke AG will install two CM surface condensers fitted with stainless steel tubing in a two-pass configuration (*Table 3*).

Type CM condensers from ABB are proven in operation worldwide. The CM condenser is the type most commonly used in medium- and high-output power plants. Its size makes the condenser, alongside the steam turbine and generator, one of the most important and critical components in the turbine building of the power plant.

The chief condenser parameter is its pressure, which represents the turbine backpressure and thus plays a significant role in the overall efficiency of the plant and in the generator terminal rating. As a manufacturer of steam turbines and condensers, ABB is in the position of being able to guarantee optimum matching of these two key components.

CM condensers are of the 'church-window' type and of modular design. The characteristic feature of the CM condenser is the arrangement of the tubes in identical configurations, combined to form separate bundles. The shape and arrangement of the bundles was determined by experiment and using analogue models in ABB's fluid mechanics laboratory. With the help of computer models, a series of standardized bundles that cover the full range of large condensers **7** was developed. Optimum solutions are possible in every case, since all the geometric requirements are met by appropriate selection of the bundle and variation of the number of bundles and tube length.

A tube bundle consists of the upper and lower bundle sections and an air-cooler section. The steam passes via the precooler and orifices into the air-cooler, where vacuum pumps deaerate the steam via venting ducts. Two air-coolers per tube bundle ensure optimum degassing of the condenser.

Since the steam enters the bundle from every side, velocities and pressure loss on the steam side are low. Uniform loading of the bundle leads to high heat transfer coefficients.

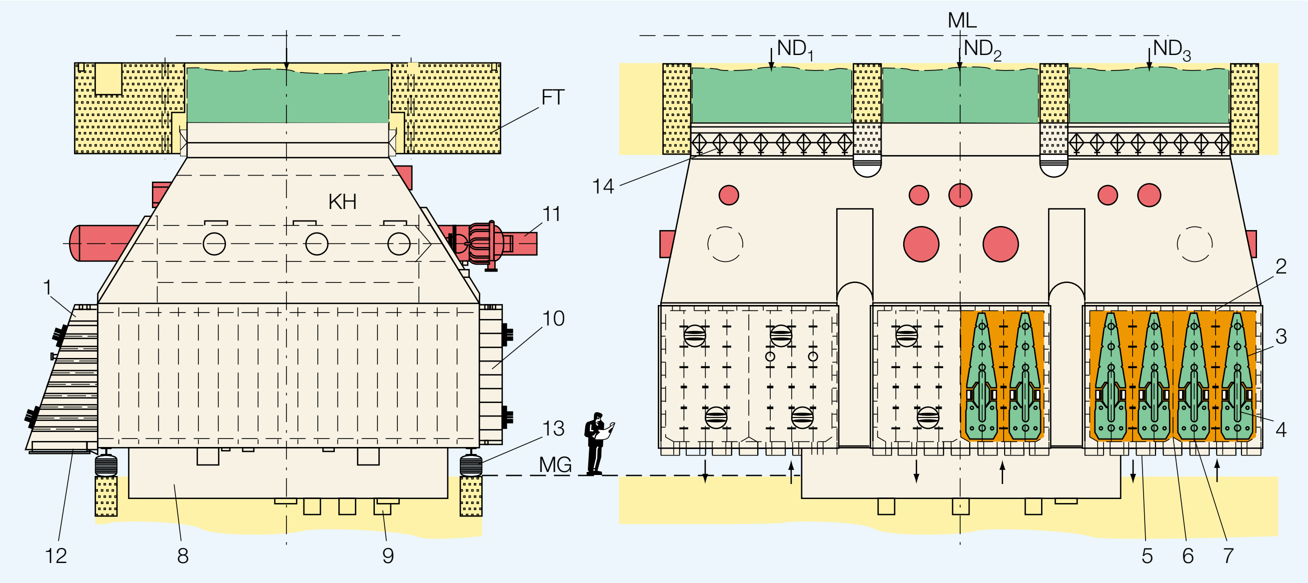
The steam entering the bundle from below flows counter to the direction of the condensate percolating from above. Due to the intensive contact with the steam, degassing and the increase in condensate temperature are an optimum. Below the bundle the steam has a lower velocity than in the exhaust steam nozzles and the upper bundle tubes; the temperature and static pressure are thus higher. As a result, the condensate in the hotwell assumes a higher temperature than the saturation temperature corresponding to the condenser pressure.

Table 3:
Technical data of the turbine condensers

Dissipated heat		890.76	MW
Condenser pressure		0.038	bar
Cooling water	– volumetric flow	20.9	m³/s
	– temperature	16.4	°C
	– flow rate	1.95	m/s
Heat-exchanger	– surface area	54,950	m²
	– material	X 5 CrNiMo 17 12 2	
External dimensions W/H/D		22/15/18	m
Total weight, empty		1,140	t

CM turbine condenser **8**

FT	*Foundation*
KH	*Condenser neck*
MG	*Turbine house, ground floor*
ML	*Turboset center line*
ND_{1-3}	*Exhaust-steam, LP turbines 1–3*
1	*Inlet water box*
2	*Steam chamber*
3	*Bundle, upper part*
4	*Bundle, lower part*
5	*Precooler*
6	*Air cooler*
7	*Air-suction duct*
8	*Hotwell*
9	*Pipes to condensate pumps*
10	*Outlet water box*
11	*Steam dump device*
12	*Cooling-water pipe*
13	*Spring support*
14	*Anchorage compensator*



Turbine condenser module for the Lippendorf lignite-fired power plant being fabricated at ABB Kraftwerke GmbH, Berlin **9**

This feature of the CM condenser has a positive effect on heat consumption and is known as 'negative subcooling'.

The optimum arrangement of the condenser tubes ensures that heat transfer coefficients are high at full and partial load, resulting in low condenser pressures. The excellent thermal characteristics result in a considerably smaller heat-exchanger surface area being needed. This has a positive effect on the heat rate of the power plant and ultimately results in reduced costs for the machine hall.

Besides these outstanding thermodynamic properties, the modular concept offers many advantages in the equipment design and fabrication areas.

The CM condenser is joined mechanically to the turbine and supported on springs resting on a baseplate. The steam section of the condenser is connected via the condenser neck to the exhaust-steam ends of the three LP turbines **8**. The connection to the middle LP exhaust-steam casing is of rigid design. Anchored bellows compensate for the differences in thermal expansion in the connections to the front and back LP outer casings.

The condenser cooling-water system has a double-flow configuration, divided into three sections and with three connections (DN 2000). A tube-cleaning system is provided for each section.

Two of the condenser connections have two steam bypass systems through which the steam from the boilers passes directly to the condenser during start-up, etc. ABB steam dumping devices integrated in the condenser neck in the region of the front and back LP outer casings ensure smooth transit to the condenser. Besides protecting the condenser tubes and LP turbine sections from the high-energy steam, this arrangement also keeps the noise level comparatively low.

Due to the large size of the condensers, the pre-assembled modules **9** have to be built to the highest quality standards. The work carried out during final assembly in the power plant is thereby reduced to a minimum.

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