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The 125 MW Combined Cycle Power Plant ''Korneuburg-B''. Design Features, Plant Performance and Operating Experience

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In January 1980 NEWAG, an Austrian utility, commissioned a natural gas fired 125 MW combined cycle unit at Korneuburg near Vienna. The plant has some interesting characteristics which have led to an exceptionally high net efficiency during the first 19 months of operation though the plant is started twice daily within 30 minutes and is used for medium/peak load shaving. A detailed description of the fully automized plant systems, their main components, the design and test data, as well as the operational experience are given in this paper. The Korneuburg plant can be considered as an example of the present state of the art of power plant engineering.

INTRODUCTION

Because of the steep rise of the market prices of liquid and gaseous fuels during the past years, countries all over the world are trying to overcome the effects to their economies of primary energy imported at high cost.

Measures being adopted are the search for local and alternative energy resources and the forced application of coal. The most important, short term, is the improvement of thermal cycles to obtain essentially better utilization of the fuels used for power generation.

With the aim of improving the efficiency, steam cycles with supercritical live steam parameters and double-reheat cycles are under development (1).

The best thermal efficiencies are however only achievable with the combination of a topping and a bottoming cycle (2); the first working with a high or medium temperature heat input, the second with a heat exhaust at a very low temperature. This allows for highest Carnot-efficiencies. The combination of the proven open gas turbine cycle and the closed steam turbine cycle, therefore offer a simple and ideal solution, if suitable fuels for gas turbines are available. With combined gas/steam turbine plants, it is possible to generate electricity with lowest fuel consumption and highest profit.

Noteworthy among the multitude of combined-cycle plants which were built recently are three from BBC Brown, Boveri & Company, Ltd., because they have the highest plant efficiencies ever recorded.

The three stations are the 'Donge' plant of PNEM (Provinciale Nordbrabantsche Elektriciteits Matschapij, Geetruidenberg, Netherlands) (4), the 'Korneuburg' plant of NEWAG (Niederoestereichische Elektrizitätswerke AG, Maria Enzersdorf-Suedstadt, Austria) (5), and the 'Hagen-Kabel' plant of Elektromark AG (Hagen, F.R. of Germany) (6). Table A shows the main data of the three plants. All three have common facets: they are based on the same gas turbine frame size and the systems are similar. The experience gained from the Donge plant has been utilized for the subsequent units. For all three plants Brown Boveri have worked with different steam generator manufacturers and were responsible for the entire layout, design, engineering and the erection and commissioning of the power plant equipment.

'NEWAG' AS PIONEER FOR COMBINED-CYCLE

In 1960, NEWAG, an Austrian utility, put in service at Korneuburg in Austria their 75 MW combined-cycle plant 'Korneuburg-A': one of the first of its type to be built in Europe. The idea was to produce electricity from natural gas which had recently become available but for which no consumers could be found. The plant consisted of two 25 MW gas turbosets and a 25 MW steam turboset supplied by Brown Boveri and a heat recovery steam generator with supplementary firing (7).

By present day standards, this first combined-cycle plant evidenced only moderate efficiency. The gas turbine at that time could only be operated at relatively low gas inlet temperatures (thus yielding only a modest Carnot efficiency of the combined-cycle). However with base-load plant operation from 1960 - 1974 an average of 6000 hours per year under full load conditions were achieved. From 1974 onwards the plant

Contributed by the Gas Turbine Division of the ASME.

Table A
Main data of the combined-cycle power plants
Donge, Korneuburg-B, Hagen-Kabel.
All data given for an ambient temperature of 15 °C (59 °F)

Plant	Donge	Korneuburg-B	Hagen-Kabel	Units
Gas turbine size	1 x type 13	1 x type 13	2 x type 13	-
Year of commissioning	1975	1980	1981	-
Gas turbine output	76.6	81.0	2 x 77.5	MW
Steam turbine output	47.3	49.0	88.0	MW
Total gross output	123.9	130.0	243.0	MW
Total net output	122.7	128.8	240.0	MW
Net heat rate (IS)	7,895	7,717	8,000	kJ/kWh
(US)	7,483	7,314	7,582	BTU/kWh
Net efficiency	45.6	46.6	45.0	%
Cooling system	fresh water	fresh water	cooling tower	-

became too uneconomical to operate, mainly due to rising fuel costs originated by relatively low net efficiency and was therefore only used to cover peak-load demand. NEWAG also commissioned in 1965 another combined-cycle plant 'Hohe Wand' with a capacity of 75 MW (8).

In 1975 NEWAG set up a project study for the replacement of Korneuburg-A and thereby the investigation of the means of more efficient utilization of the high grade natural gas, which had become a valuable commodity. NEWAG came to the conclusion that a modern combined-cycle, without supplementary firing, would be the optimum solution to meet their requirements:

- maximum utilization of high grade natural gas (plant application to cover base-load demand).
- low initial capital cost per kW installed capacity (i.e. efficient utilization of space available at site).
- fast plant start-up and shutdown capability (future application to cover medium-load demand).
- minimum possible adverse effects on the environment (low exhaust gas emissions, noise limitation and low cooling water requirements due to existing and expected further legal restrictions in the future)
- automatic start-up, shutdown and monitoring of operation (minimum personnel requirements).
- high plant availability and reliability (i.e. by use of well-proven components and simple system design).
- utilization of available space in the existing plant building.

PROJECT STUDY AND TENDER PHASE

Functional enquiry specifications, based on information received from various suppliers for the combined cycle power plant, were issued by NEWAG. The supplier would be responsible for the entire combined-cycle power generating system comprising gas and steam turbosets, heat recovery steam generator, piping and all auxiliaries, the control, monitoring and protection systems, the 10,5 kV switchgear installation, including the generator heavy current bus-ducts to the main transformers and the low voltage equipment. From the four bids submitted, the consortium BBC Brown Boveri/Waagner Birō was selected and the contract awarded in August 1977.

Waagner Biró of Graz, Austria, was to supply the heat-recovery steam generator. Brown Boveri of Baden, Switzerland, was responsible for the technical leadership, co-ordination of project implementation and for the plant layout. NEWAG took over the civil engineering. The civil work was executed by local contractors.

PROJECT PHASE

In the layout and design phase, engineers of the supplier and customer worked closely together thus combining previous operating experience from the first Korneuburg combined-cycle plant and the supplier's general experience, in particular with the highly efficient 125 MW Donge plant.

The flow diagram of the combined-cycle plant developed is shown in Fig. 1. The applied plant system is a typical dual-pressure system which allows for an optimized exergetic utilization of gas turbine waste heat in the heat-recovery steam generator. Since natural gas with a very low content of sulphur is used as a fuel, an extremely low flue gas temperature of 95 °C (203 °F) can be admitted at the steam generator outlet, without major danger of dew-point corrosion.

The steam cycle is of a simple design. The steam leaving the single-cyclinder turbine is condensed in a river-water-cooled steam condenser. Preheating of the boiler feed water is done in a single stage by means of a direct-contact feedheater/deaerator. Because of the low flue gas temperature at the steam generator outlet, the pressure in the deaerator is below the atmospheric pressure (vacuum). For the plant start-up the steam turbine is by-passed by a steam by-pass which allows the steam produced in the steam generator to be discharged directly into the condenser.

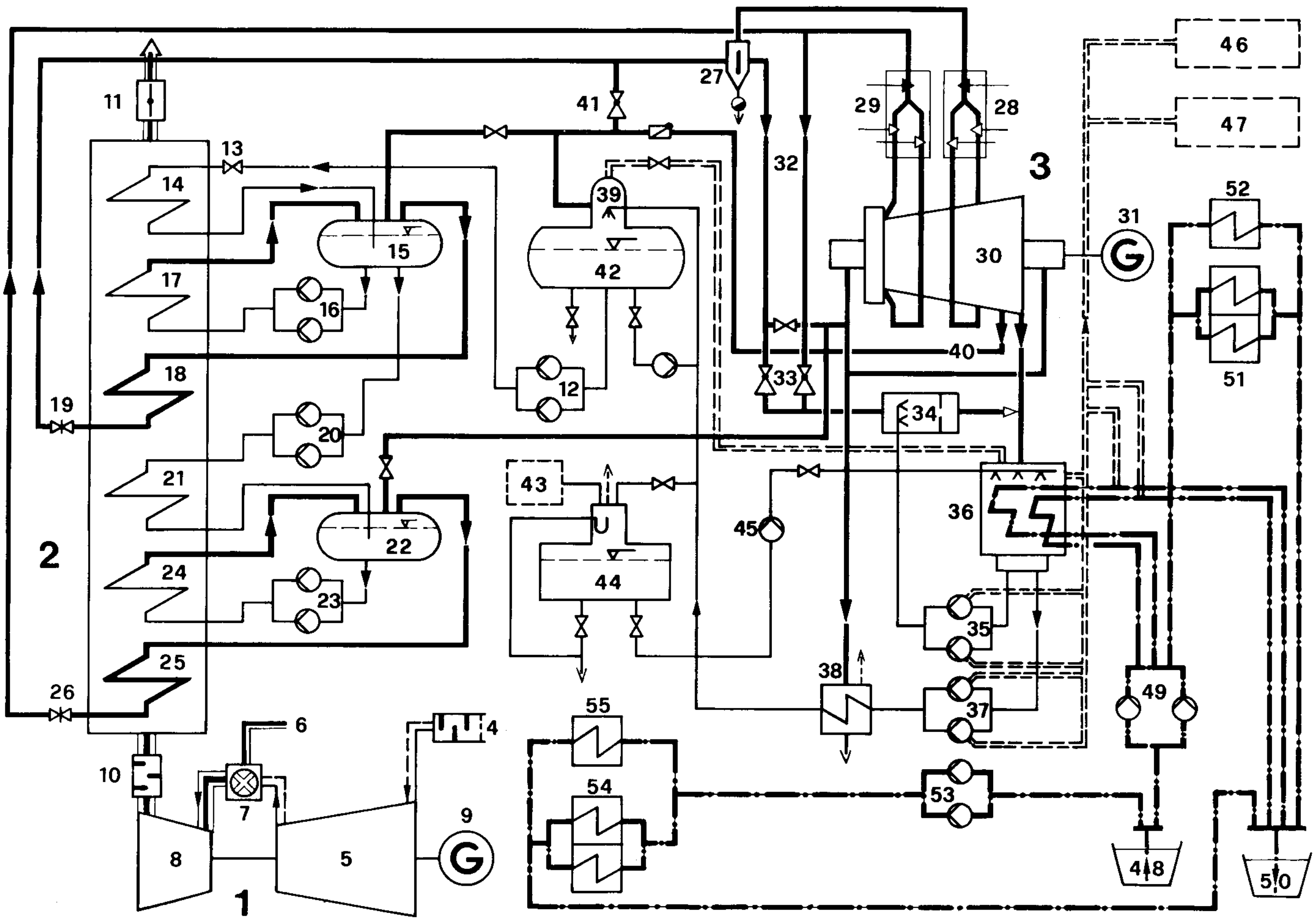


Fig. 1 - General flow diagram of the 125 MW combined-cycle power plant Korneuburg-B

- ------ Air
- ══════ Fuel
- ══════ Exhaust gas
- ━━━━━━ Steam
- ────── Condensate
- ====== Vacuum
- •—•—• Cooling water

1 Gas turboset
2 Heat-recovery steam generator
3 Steam turboset
4 Air intake filter
5 Turbocompressor
6 Fuel feed
7 Combustion chamber
8 Gas turbine (GT)
9 GT turbo-generator
10 Exhaust silencer
11 Stack with rain damper
12 LP feedwater pumps
13 LP feedwater control valve
14 LP economiser
15 LP drum
16 LP circulating pumps
17 LP evaporator
18 LP superheater
19 LP steam line
20 HP feedwater pumps
21 HP economiser
22 HP drum
23 HP circulating pumps
24 HP evaporator
25 HP superheater
26 HP steam line
27 LP water separator
28 LP stop and control valve
29 HP stop and control valve
30 Steam turbine (ST)
31 ST turbo-generator
32 LP and HP steam bypass
33 Steam bypass control valves
34 Injection steam desuperheater
35 Injection water pump
36 Exhaust steam condenser
37 Condensate pumps
38 Auxiliary condenser
39 Deaerator/feedheater
40 Bled steam line
41 Back-up steam bypass
42 Feedwater tank
43 Boiler water treatment plant
44 Boiler water tank
45 Make-up water pump
46 Start-up vacuum pump
47 Operating vacuum ejectors
48 Riverwater intake for cooling
49 Main cooling water pumps
50 Cooling water return to river
51 ST generator air cooler
52 ST oil cooler
53 GT cooling water pumps
54 GT generator air cooler
55 GT oil cooler

The deaerator is heated with bled steam from the steam turbine or with steam from the low pressure boiler drum, depending on operational conditions.

TECHNICAL DATA OF THERMAL COMPONENTS

Table B provides a summary of technical data of the Korneuburg-B unit. The heat and massflow balance is shown in Fig. 2. The plant was designed as a base load station in order to achieve maximum utilization of the high grade natural gas. NEWAG intended to cover base-load demand for the next few years, running the 125 MW combined-cycle unit at full load up to 6000 hours per year. It was envisaged operating the plant to cover medium-load demand when the new 2 x 350 MW base-load coal fired steam power station of NEWAG, near Vienna, went into operation (scheduled for 1985). In view of the required medium-load capability, the plant had to be designed for fast start-up and shut-down.

The gas turbine

A standard industrial gas turbine, of the proven

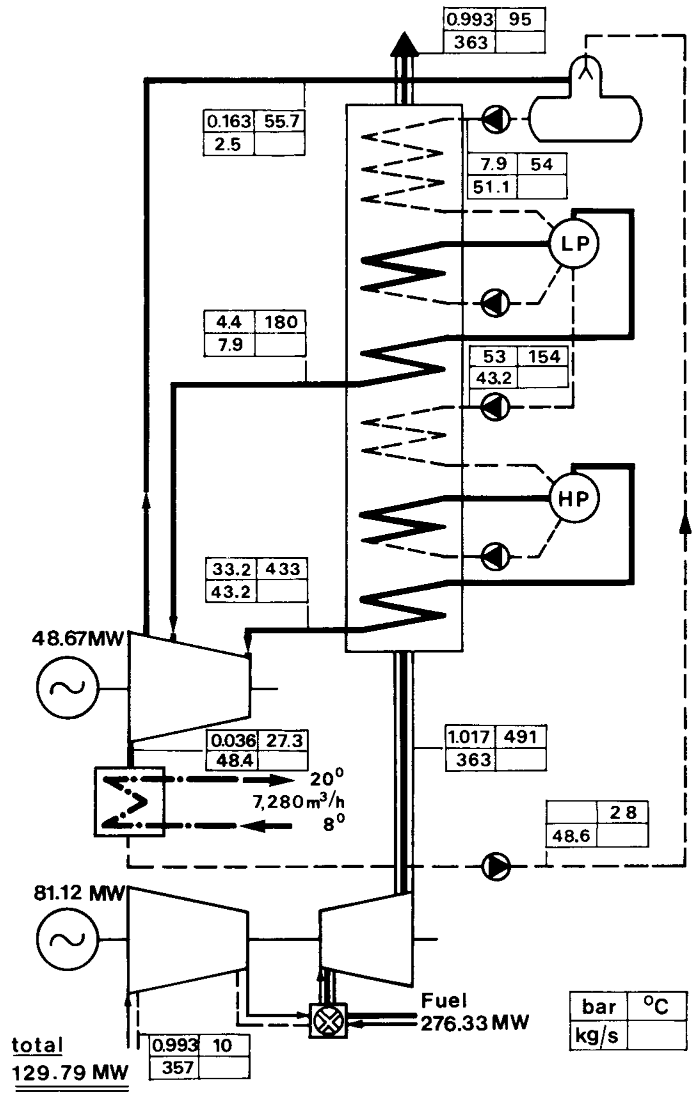


Fig. 2 - Heat balance of the Korneuburg-B Plant

Gross efficiency : 47.81 % (at generator terminals)
Net efficiency : 46.62 % (at transformer terminals)

Brown Boveri Type 13 design, was supplied for Korneuburg-B. Fig. 3 shows a cross-section of the gas turboset.

A common one-piece rotor of welded disc design is used for the highly efficient axial flow compressor and the heavy duty gas turbine. The rotor carries a 17-stage compressor blading and a 5-stage reaction type gas turbine blading. The turbine blade roots, the turbine stator casing, certain inlet guide vanes and inlet blades are air-cooled. Cooling of the turbine rotor is the most important design feature. All parts must be kept within their safety temperature limits, but at the same time cooling air must be used very efficiently while minimizing cycle efficiency losses. The cooling is accomplished so efficiently that a maximum temperature of 450 °C (842 °F) is not exceeded, therefore allowing manufacture of the rotor from ferritic Cr-Mo-V steel. The cooling principle allows the leading away of the heat penetrating the rotor closely underneath the surface.

Table B

Performance data of the 125 MW combined-cycle plant Korneuburg-B for ambient temperature 10 °C (50 °F) and barometric pressure 993 mbar
Temperature of cooling water 8 °C (46.5 °F)

Gas turboset	Reading	Units
Gas turbine	Type 13	-
Fuel	Natural gas	-
Calorific value LHV	36.7	MJ/m³N
Power supplied in the fuel	276.33	MW
Efficiency of the gas turbine	29.36	%
Output at generator terminals	81.12	MW
Exhaust gas mass flow	363	kg/s
Exhaust gas temperature	491	°C
Heat-recovery boiler		
Exhaust gas temperature at boiler outlet	95	°C
Exhaust gas pressure drop in boiler	20	mbar
Feedwater mass flow	50.9	kg/s
Feedwater temperature	54	°C
LP steam mass flow	7.9	kg/s
LP steam temperature	180	°C
LP steam pressure	4.4	bar
HP steam mass flow	43.2	kg/s
HP steam temperature	433	°C
HP steam pressure	33.2	bar
Steam turboset		
Vacuum in condenser	0.036	bar
Cooling water temperature	8.0	°C
Cooling water volume flow	7280	m³/h
Output at the generator terminals	48.67	MW
Combined-cycle unit, total		
Total power output (gas and steam turbines)	129.79	MW
Consumption of station auxiliaries*	–0.96	MW
Net output of the plant	**128.83**	MW
Net heat rate	**7721.8**	kJ/kWh
Net overall efficiency of plant	**46.62**	%

* Referred to measurement on the 10.5 kV side of the transformers

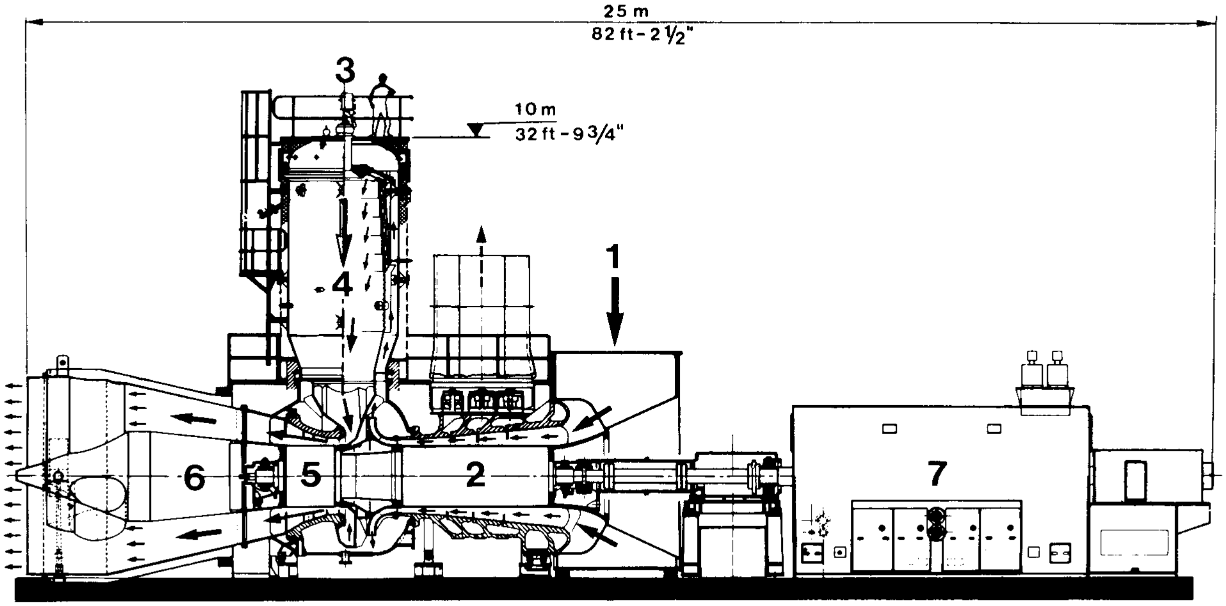


Fig.3 -Section through gas turbine type 13
1 air inlet, 2 compressor, 3 dual fuel burner (gas, oil), 4 combustion chamber, 5 gas turbine, 6 exhaust gas diffuser, 7 air-cooled turbogenerator.

Heat shields are used for both the rotor and the stator (to protect the blade carrying elements from high temperature), and give temperature protection not only during continuous operation but also absorb the first thermal shock during start-up.

The stator blade carrier which is free to expand and is centered inside the outer casing is also covered with segmented heat shields to protect it against high temperatures, and is cooled by relatively 'cold' air.

The casing of the gas turbine and compressor are horizontally split to maintain easy access for inspection. The shaft runs in only two journal bearings. The main thrust bearing is of the mitchell type. All bearings are babbited and pressure lubricated with standard turbine oil.

The generator of the gas turboset is driven at the cold end side (compressor inlet). The axial outlet of the gas turbine exhaust facilitates the space saving connection to the heat-recovery steam generator and avoids unnecessary pressure drop in the exhaust duct.

The single double-flow type combustion chamber, mounted vertically on top of the gas turbine, can burn liquid fuel as well as gas. The one burner simplifies control and at the same time improves reliability. The large volume combustion chamber ensures a good temperature profile, good flame stability and good accessibility to all parts exposed to high temperatures, including the first gas turbine stage.

A solid coupling between turbine and generator avoids maintenance and reliability problems associated with flexible and gear type couplings.

The gas turbine set is very compact owing to the direct drive of the 3,000 rpm, 10,5 kV generator with a totally enclosed air cooling system.

The heat-recovery steam generator

The hot turbine gas is cooled down from about 500 °C (932 °F) to 95 °C (203 °F) in the heat exchangers of the heat-recovery steam generator. A dual-pressure boiler design was adopted to ensure economically optimal transfer of the exhaust gas heat energy content to the water/steam cycle of the steam turbine. At full gas turbine load, two coupled economizer/evaporator/superheater systems produce superheated high pressure live steam of approximately 33 bar/438 °C (479 psig/820 °F) and superheated low pressure live steam of 4.4 bar/182 °C (64 psig/360 °F).

The steam generator was manufactured by Waagner-Biró. Its basic components are:

- horizontal exhaust gas ducting with a 90° bend at the very entrance to the steam generator.
- heat recovery generator with corresponding high and low pressure systems
- flue gas stack with an electrically operated bad weather safety flap at its upper section for protection of the unit.

Fig. 4 shows a cross section of the heat recovery generator. The total heat exchange surface area of the boiler exceeds 75,000 m^2 (89,700 sq.yds.). The steam generator is built as a suspended construction.

Special design features were necessary on account of the short plant start-up times. The boiler unit design permits exceptional dry operation, i.e. without water in the steam generator, at gas turbine exhaust temperatures in the range of 500 °C (932 °F). The changeover to dry operation does not take place automatically. It is first necessary to drain the boiler with both drain and vent valves open in dry service. This design feature avoids having to provide a bypass stack with its energy losses at the bypass dampers. The system of the heat recovery steam generator is shown in Fig. 1.

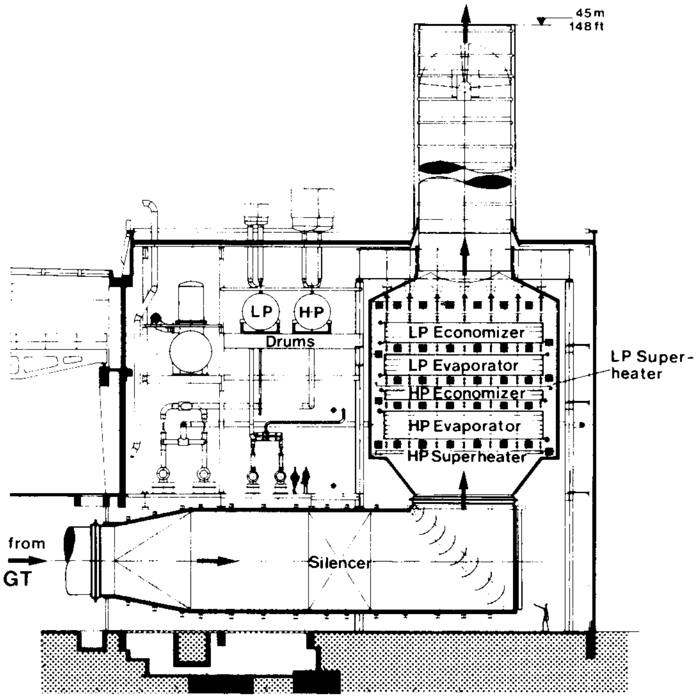


Fig. 4 - The heat-recovery steam generator of the 125 MW combined cycle plant Korneuburg-B.

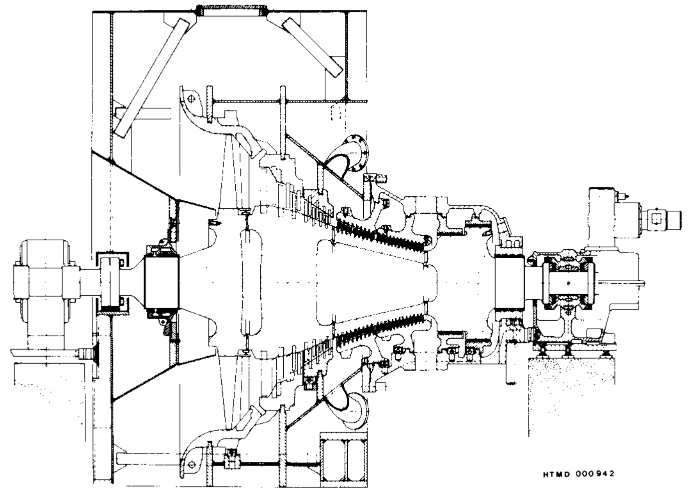


Fig. 5 - The 50 MW dual-pressure condensing steam turbine with its typical Brown Boveri design.

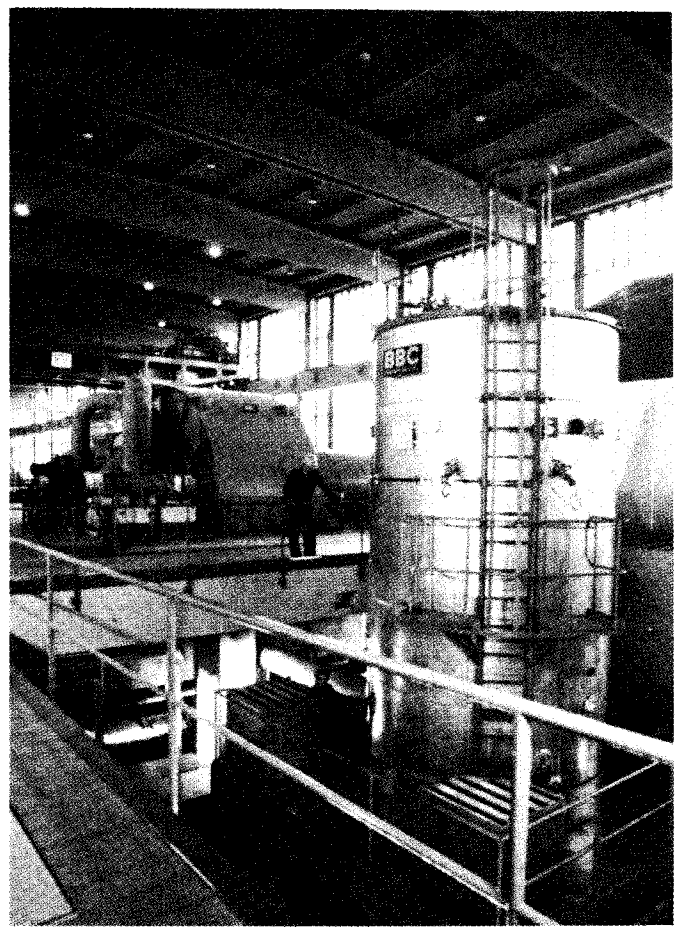
The steam turbine

This plant component basically consists of a single cylinder dual-pressure condensing steam turbine of a rated output of 50 MW connected to a steam condenser with an operating vacuum of 0.036 bar (1.06 in. Hg) attained at a cooling water temperature of 8 °C (46.4 °F).

For better efficiency at full and partial load conditions, the turbine has no control stage and operates with sliding (variable) pressure. The turbine is from Brown Boveri's programme of medium sized steam turbines based on a modular system, whereby a very compact optimized turbine design can be achieved and standardized blades are employed. Fig. 5 shows a longitudinal section of the condensing steam turbine. The steam turboset is provided with the necessary plant auxiliaries. Most of the former plant's cooling water system was retained for the new plant. Despite the increase in plant output from 75 MW to 125 MW, the cooling water flow requirement of 7,300 m^3/h (260,000 cu.ft./hr) for the new plant is slightly less than that of the old.

Fig. 6 gives a view of the 50 MW steam turbine with the gas turbine combustion chamber visible in the foreground.

Fig. 6 - View of the steam turbine from the gas turbine side.



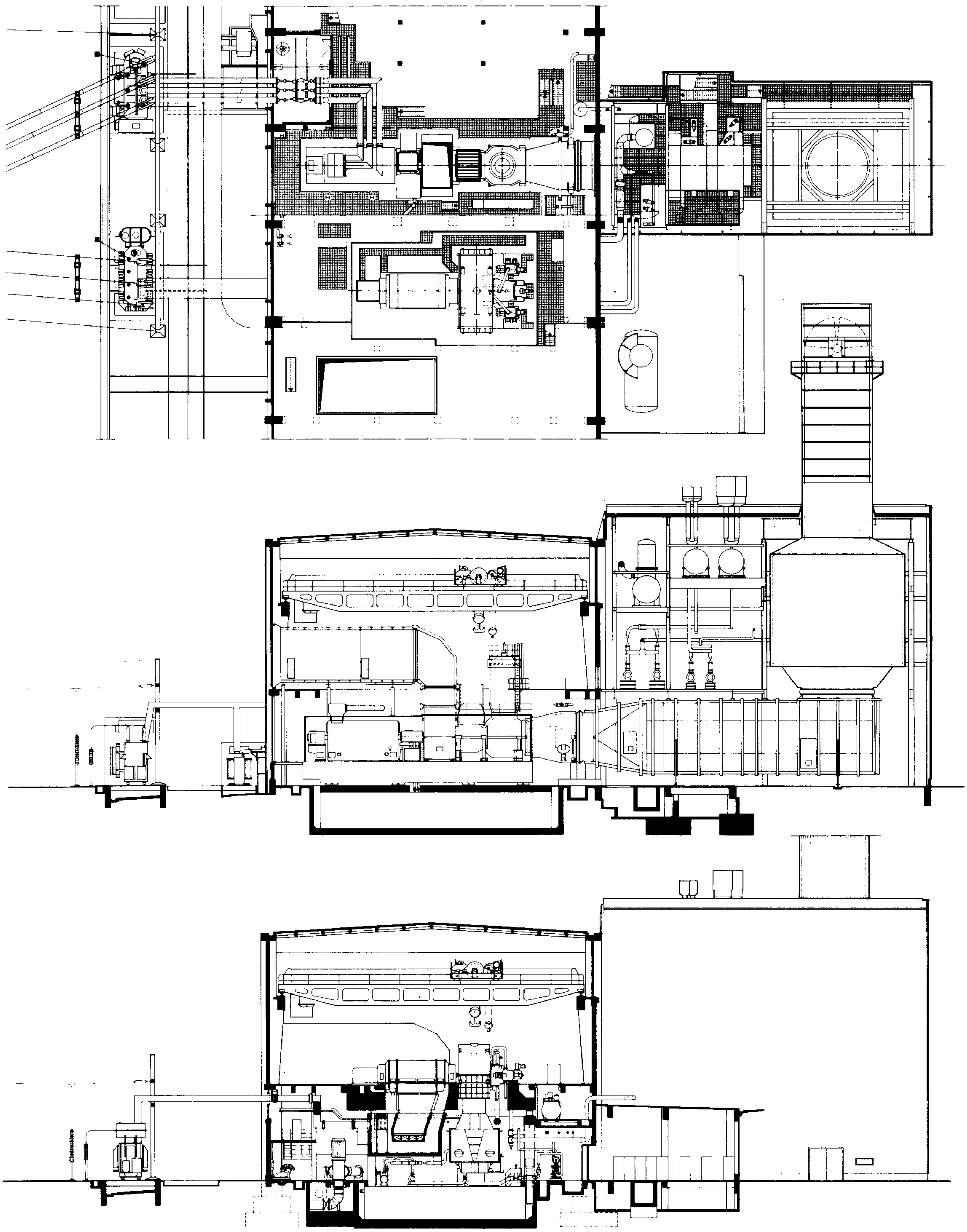


Fig. 7 - The arrangement of equipment in the 125 MW combined-cycle plant Korneuburg-B

PLANT LAYOUT

The plant layout drawings, Fig. 7, show the compact and space saving arrangement in the existing power plant building. However, the plant components are easily accessible and serviceable. The centrelines of the two turbosets are parallel and perpendicular to the centre line of the building. The steam turboset is mounted on a low tuned foundation at the same level as the other steam turbines in the building. Fig. 8 shows the arrangement of the gas turbine and the steam turbine in the power plant building. The condenser, located under the steam turbine, is also purposefully arranged (Fig. 9). In the upper part of the condenser the steam bypass with the desuperheater station is visible.

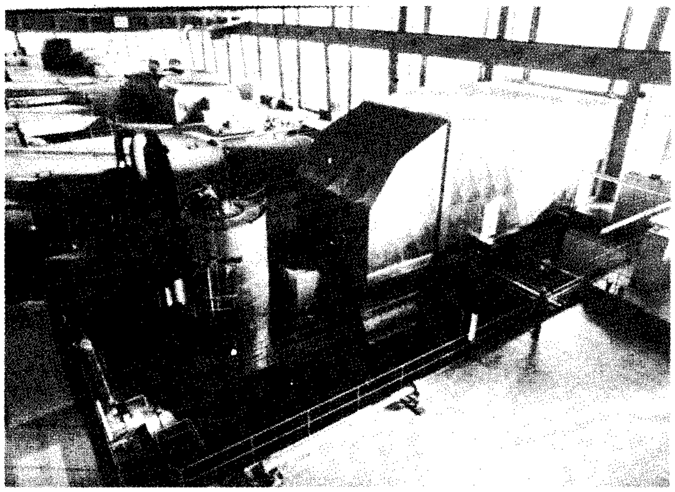


Fig. 8 - The gas turbine and the steam turbine are harmoniously integrated in the power plant building.

OPERATIONAL CONCEPT

To ensure fullest possible utilization of the natural gas, the 125 MW Korneuburg-B power plant operates permanently at highest achievable full-load. Similarly, so as to obtain effective economic benefit from the very high plant efficiency, it is not intended to run the plant at part-load, not even when operated at medium-load duty.

To use the plant as a medium-load power station, it must be possible to start up the combined-cycle plant daily from standstill to full-load in the shortest possible time. In addition to special design features, therefore, a modern plant process control system has been provided, by which the combined-cycle plant is started-up and shutdown under full automatic control. The Korneuburg-B plant can be started and stopped by simply pushing a button.

Rapid and prompt availability of the combined-cycle plant is a major advantage. Therefore, they are the ideal solution for thermal medium-load power generation; equally because of their short warm-starting and run-up times, they can also operate as peak-load plants without having been specially designed for the purpose.

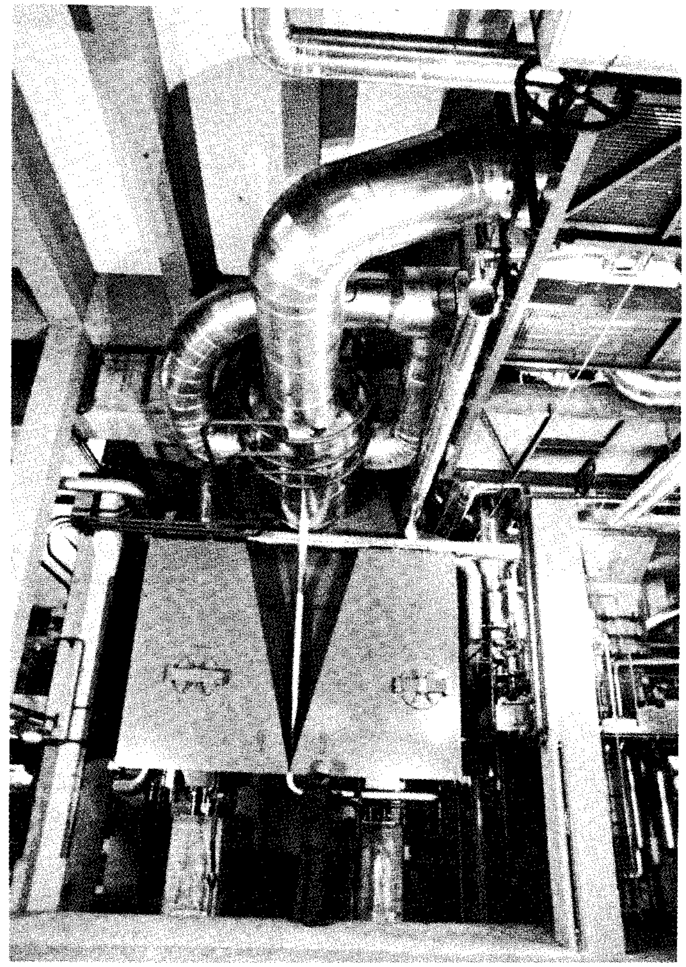


Fig. 9 - View of the condenser below the steam turbine with the desuperheater of the steam bypass.

ADVANCED PLANT CONTROL

The tasks of the overall control system for Korneuburg-B are:

- signal processing
- signal transmission
- open loop control
- closed loop control
- protection

Overall process control for the entire combined-cycle unit is provided by the PROCONTROL power plant control system including components of the Decontic ® k control system. These fully electronic systems are modular designs, thus ensuring maximum reliability with minimum maintenance requirements. The overall process control system is hierarchically subdivided into several control levels as shown in Fig. 10.

The combined-cycle plant is operated and monitored from a control desk in the central control room (see Fig. 11). The control equipment and instrumentation provided permit fully automatic start-up and shutdown of the gas turboset, heat recovery steam generator, steam turboset and the auxiliaries. The operating personnel are kept informed of the momentary state of of the plant and can take over manual control from the main control room in the event of an emergency or

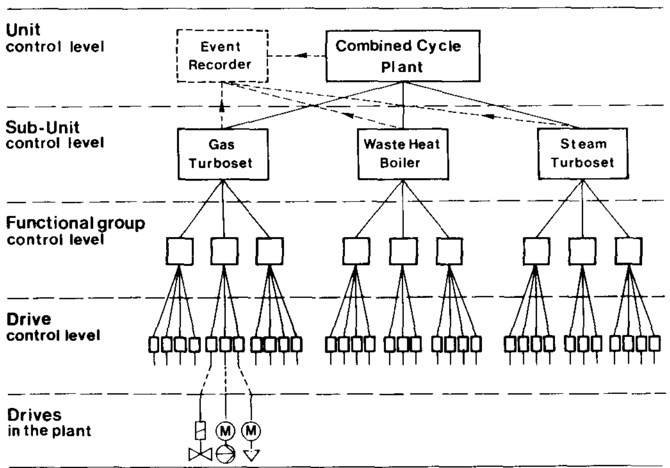


Fig. 10 - The hierarchical structure of the PROCONTROL/Decontic® k power plant control system

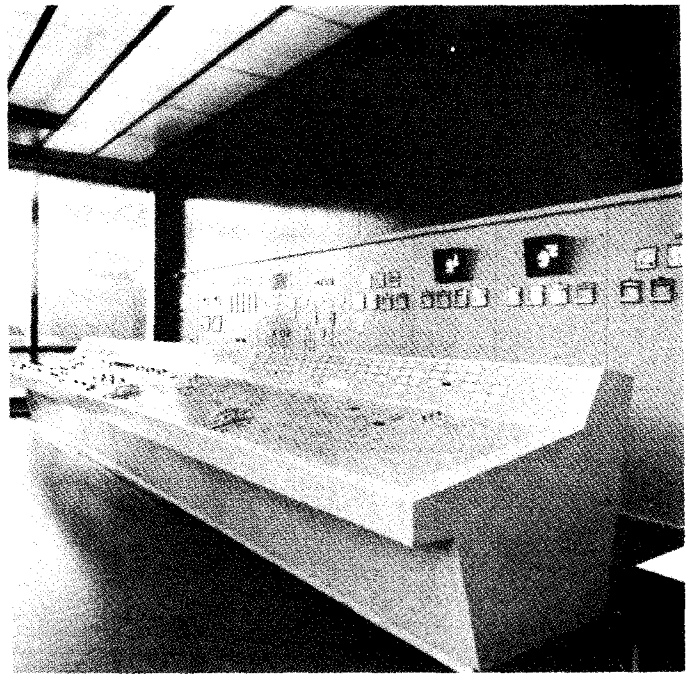


Fig. 11 - The control desk with the mimic plant diagram in the control room of the Korneuburg plant

operating trouble. A functionally arranged control desk with a mimic diagram of the combined-cycle plant provides the operators with an overall view of all lower and higher-order systems, visual and audible alarms and fault indicators.

ELECTRICAL EQUIPMENT

The simplified single-line diagram, Fig. 12, shows the electrical system of the combined-cycle plant in the Korneuburg power station complex. The air-cooled 110 MVA - 10.5 kV generator (alternator) of the gas turbine supplies by means of a 105 MVA - 10.5 / 110 kV power transformer the transmission system. The gas turbine is started by a static starting device which allows conversion of the generator into a motor. The exciter equipment, comprising a transformer and a fully controlled thyristor bridge circuit is supplied from the generator. Electric power for starting of the gas turbine is obtained from the 110 kV system via the power transformer of the gas turbine unit. The power is fed from the generator to the transformer by means of a separate phase-segregated heavy current bus duct (coaxial metal tubes).

The air-cooled generator of the steam turboset has an apparent pwer rating of 56.25 MVA and a voltage rating of 10.5 kV. The generator is excited by a rotating brushless exciter system comprising rotating rectifiers which are supplied by the 3-phase main and pilot exciters. The generator output is fed directly to the 56 MVA - 10.5 / 110 kV power transformer of the steam turbine unit via three-phase conductors in common self-cooled aluminium enclosure.

Under normal combined-cycle plant operating conditions, the plant's own requirements are covered by the gas turboset. The cooling and feedwater pumps are supplied directly from the 6.3 kV busbar. For safety reasons, the 6.3 kV and 400 V systems are coupled to those of the steam power plant in the same building complex. As an aid to understanding the diagram, it should be mentioned that the 400 V supply requirements for both 280 MW and 77 MW steam turbosets and the 25 MW reserve gas turboset (from the former plant), are catered for by the three 6.3 kV/400 V auxiliary transformers shown in the single-line diagram.

EXECUTION OF THE WORK

After the contract award in August 1977, erection started 19 months later in March 1979 and the commissioning began in January 1980. On May 1st, 1980, in accordance with the contract schedule, the plant was ready for four week's trial run. This was completed at the first attempt without any problem, so that the provisional acceptance certificate was issued by NEWAG at the beginning of June 1980.

ACCEPTANCE TESTS

Since, in practice, great differences exist in the methods applied for acceptance tests (which verify the guaranteed performance data), it is necessary to explain the applied methods, i.e. as such high efficiencies are involved as featured by the combined-cycle plant Korneuburg-B.

Working closely together with the suppliers, the plant owner NEWAG and ARSENAL (Federal Material Testing and Research Institue of Austria), the tests were carried out in 1980 from June 12th - 14th.

The tests were performed in order to prove the guaranteed data of electrical output and the heat rate of the combined-cycle unit. The rules and regulations of DIN (German Standards) and VDE (German Association of Electrical Engineers) were applied, i.e.:

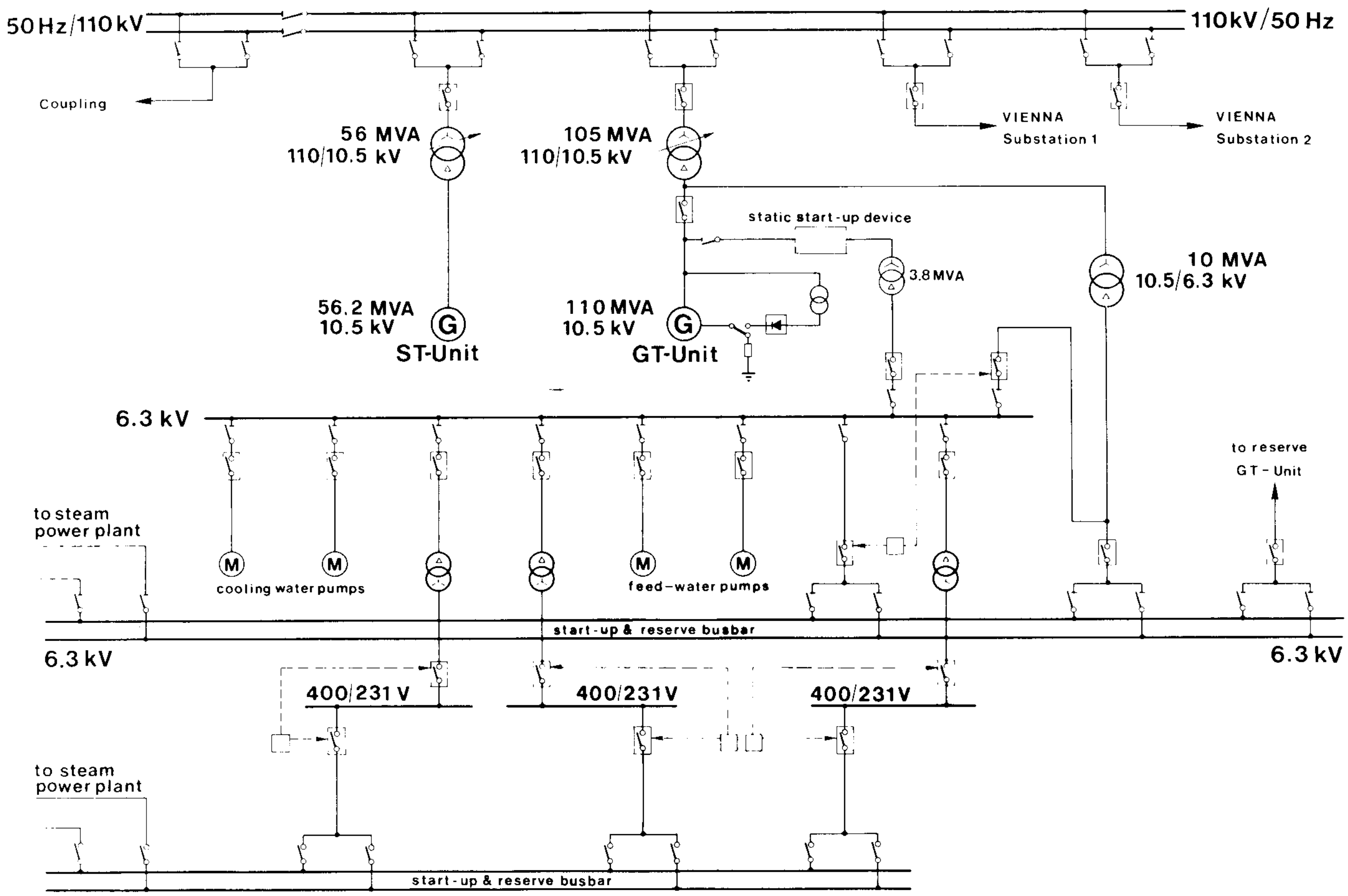


Fig. 12 - Single-line diagram of the electrical equipment of Korneuburg-B

DIN	1319	Basic principles of measuring techniques
DIN	1952	Flow measurement with standardized metering nozzles, orifices and Venturi-tubes
VDE/VDI	3511	Standard for technical measurement of temperatures
DIN	4341	Regulation for gas turbine performance tests
DIN	1943	Regulations for steam turbine performance
DIN	1942	Regulations for steam generator performance tests

The guaranteed performance data was given for an ambient temperature range 0 - 35 °C (32/95 °F) but during the test it was only possible to operate the plant at temperatures between 14 and 28 °C (57/82 °F). It was therefore necessary to apply theoretical correction diagrams in order to convert the measured values into values corresponding to the ambient temperatures of the guaranteed values.

The important measurements for the proof of the guaranteed data such as electrical output, fuel flow, heating value of the fuel and environmental conditions have all been carried out by NEWAG together with ARSENAL.

Test equipment

For the measurement of the electrical output, high accuracy instruments and precision wattmeters were used. Measurement of the natural gas flow was by means of a standard orifice metering device, which is permanently built into the gas duct, and was under the supervision and responsibility of ARSENAL.

In the plant diagram Fig. 13, the extent of the metering instruments applied for the acceptance tests is shown. All instruments were calibrated by the competent official authorities. The accuracy of the measurements is certified and warranted by the issued calibration curves and tables.

Acceptance test results

The result of the measurements for full load operation of the plant at 10 °C (50 °F) ambient temperature is compiled in Table B. The measured mean values of the test series are adjusted based on the calibration curves or tables of the testing instruments and the theoretical correction curves.

The results of the other guarantee points, also measured at full load, and the comparison with the guaranteed values of the contract are shown in Table C.

The net efficiencies which are based on the lower heating value, depending on the ambient temperature, achieve at full load 46.32% - 46.62%. At peak-load over 140 MW and higher ambient temperatures a net efficiency of more than 47% is achieved by the ./.

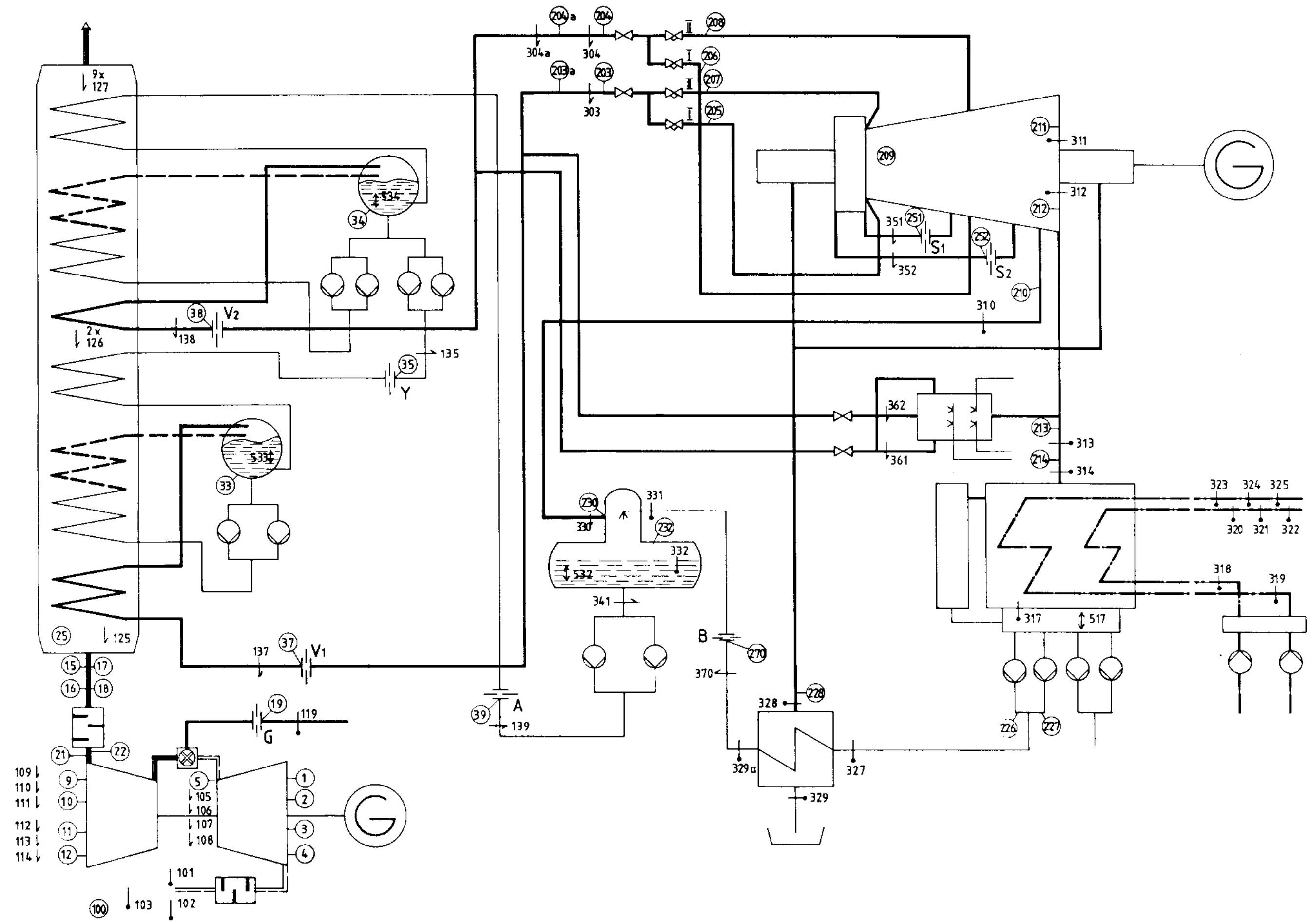


Fig. 13 - Diagram of metering points applied for the Korneuburg-B acceptance tests

Symbols:

- (201) Pressuremeter
- Thermocouple element
- Thermometer (mercury)
- Levelmeter
- Flowmeter

Table C

Comparison between measured values and guarantees for the gas turbine operating at max. continuous load. Cooling water temperature 8 °C (46.5 °F) Ambient 993 mbar/10 °C (50 °F)

Air temperature	Weighting for guarantee calculation	Net output	Net heat rate	Net efficiency
°C		MW	kJ/kWh	%
0	2	134.190	7769.3	46.34
10	3	128.826	7721.8	46.62
35	1	113.115	7737.6	46.52
Measured mean value		**127.996**	**7740.3**	**46.51**
Guaranteed mean value		124.213	7800.0	46.15
Diff. from guarantee		+3.1%	−0.8%	+0.8%

./.combined-cycle plant. The weighted mean values which were guaranteed in the contract, could be fulfilled for the power output as well as for the net plant efficiency within a good safety margin.

The top efficiency yielded by the combined-cycle plant Korneuburg-B is mainly attributable to the high grade natural gas. This, fired in the gas turbine, allows high thermal efficiency of the gas turbine and maximum heat recovery from the exhaust gas, which is cooled down to 95 °C (203 °F) by means of a carefully optimized dual-pressure steam/water cycle.

The design performance of the new 125 MW combined gas/steam turbine plant, which was confirmed in full by the test results, enables NEWAG to produce 73% more electricity from the same quantity of gas, as compared to the former obsolete plant. Therefore the replacement of obsolete plants is justified, especially when the present high level of fuel costs is taken into account.

DYNAMIC BEHAVIOUR OF THE PLANT

Because of the multitude of interdependent operational processes, it is difficult to determine theoretically the dynamic behaviour of a combined-cycle plant. On the other hand, it is necessary that a medium-load power plant, which is started up and shutdown every day, operates in a stabilized manner under all conditions. In order to verify the theoretical conditions on which the design is based, and for the demonstration of the plant's behaviour under typical

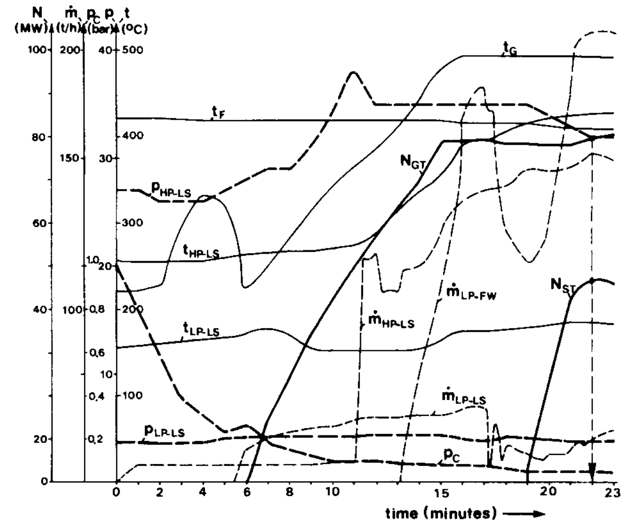


Fig. 14 - Normal automatic start-up of the still hot plant after a 1-hour standstill

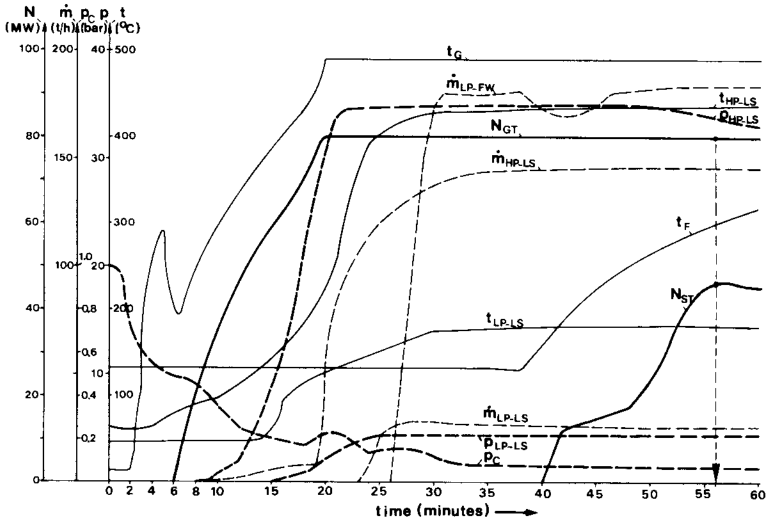


Fig. 15 - Normal automatic start-up of the cold plant after a 60-hour standstill

t_G = gas temperature at the inlet of the heat-recovery steam generator

t_{HP-LS} = high pressure steam temperature after the heat-recovery steam generator

t_{LP-LS} = low pressure steam temperature after the heat-recovery steam generator

t_F = temperature at gas turbine flange taken in the center

m_{LP-FW} = low pressure feed water flow

m_{HP-LS} = high pressure live steam flow

m_{LP-LS} = low pressure live steam flow

p_{HP-LS} = high pressure live steam pressure at steam turbine inlet valve

p_{LP-LS} = low pressure live steam pressure at steam turbine inlet valve

p_C = vacuum in the condenser

N_{GT} = power output of the gas turbine

N_{ST} = power output of the steam turbine

medium-load conditions, a series of dynamic tests were carried out. For these tests, the normal installed metering instrumentation of the plant was utilized. All measured values were registered with data recorders or printed out by the data processor of the event recording system. The following operational situations were the subject of the test series.

1. Start-up of the cold plant after a 60-hour standstill with the automatic unit control system
2. Load variation: full-load - part-load - full-load.
3. Normal plant shutdown with the automatic unit control system.
4. Start-up of the warm plant after a 14-hour standstill with the automatic control unit system.
5. Disconnection of the steam turbine generator by breaking the generator switchgear.
6. Fast unloading of the gas turbine after supposed disconnection of the low-pressure feedwater pump.
7. Start-up of the hot plant after a 1-hour standstill with the automatic unit control system.

The tests performed have demonstrated that the dynamic behaviour of the installation is kept under control at any time and that no transient operational instabilities affect the safe operation of the combined-cycle plant.

Very interesting results of the tests are shown in the diagrams for the cold and hot start of the plant (Fig. 14 and Fig. 15). After a stillstand of 1 hour the plant reaches the full output in 22 minutes. At normal starting conditions the gas turbine brings approximately 80 MW on-line in a mere 15 minutes. By fast-starting the gas turbine, this power output can be made available in only 8 minutes. In diagram, Fig. 15, the fully automatic start-up of the plant in cold state by the unit-control system is shown. After 20 minutes the gas turbine reaches full load. The steam turbine achieves full power output after 56 minutes.

These plant start-up times are much shorter than stated in the literature (9) (10) (11) and essentially contribute to improve plant economy; the uneconomical long starting times with low efficiencies in the part load range no longer exist.

PLANT OPERATING EXPERIENCE

General Experience

Initially it was intended to utilize the combined-cycle unit to cover only base-load demand, because of the new plant's high efficiency in comparison with the other NEWAG power stations. Therefore it was planned to run the unit for 6,000 - 7,000 full load service hours per year, thus utilizing the allocated natural gas contingent to maximum profit for power generation. However, a detailed study for the decade 1980/90 regarding load distribution and power generation capacity

(Table D)	Symbol	Reading	Unit
Energy produced during period	--	548,734	MWh
Period hours	PH	13,416	h
Service hours of the steam turbine	SH	4,241	h
Service hours of the gas turbine	SH	4,608	h
Equivalent lifetime hours of GT	--	5,623	h
Planned and maintenance outages	POH	1,394	h
Forced outages	FOH	166	h
Time availability of the plant	AV	88.4	%
Forced outage rate of the plant	FOR	3.5	%
Time availability of the gas turbine	AV	91.5	%
Forced outage rate of the gas turbine	FOR	2.6	%
Time availability of the steam turbine	AV	99.7	%
Forced outage rate of the steam turbine	FOR	1.0	%
Number of starts	NOS	379	-
Number of start failures of the gas turbine	NOF	23	-
Start reliability of the gas turbine	SR	94	%
number of total start failures of the plant	NOS	36	-
Start reliability of the plant	SR	91	%

Table D

Statistic availability data of Korneuburg-B
From April 24th, 1980 - November 19th, 1981.

Definitions:

Availability $AV = \frac{PH - OH}{PH}$

Forced outage rate $FOR = \frac{FOH}{SH - FOH}$

Outage hours $OH = POH + FOH$

Start reliability $SR = \frac{NOS - NOF}{NOS}$

in the NEWAG supply system has shown that the new unit can be used to greater profit to cover medium-load demand. Because of the capacity of two large steam power stations (Hohe Wand and Theiss-A) and the grid loads, which depend on the season and day of the week, Korneuburg-B is today operated as a medium-load plant.

At first sight this conclusion might not be so readily understood. However, the situation becomes clear when it is seen that the daily load diagrams of the NEWAG supply system are very different from other larger supply systems in Europe. The main reasons originate in the structure of NEWAG's supply system which covers a wide rural area with only few industrial centers. Another point is the structure of interconnection of the different Austrian networks which only allow a limited exchange of energy between adjacent supply systems.

The planning of the economical operation of Korneuburg-B is based on forecasts of the expected load conditions of the supply system and the availability of the different power plant units. A computer programme enables NEWAG to determine an optimized schedule for the economic operation of their plants.

From these explanations, the grounds for the utilization of this combined-cycle plant as a medium load plant can be understood.

Service time and availability

The operational experience, which is the subject of this part of the paper, covers the 19 month period from April 24th 1980 to November 19th 1981, beginning with the trial runs. In this period it is quite normal that certain initial deficiencies have to be eliminated.

Table D shows the relevant data for service and outage hours, with rates for time availability and forced outage for the main components and the whole plant. The calculations have made according to the methods of EEI (Edison Electric Institute) who do not normally take into consideration the operation results of the first twelve months in their plant report. Nonetheless in the present report this phase of 'bad experience' has not been excluded! The achieved high plant availability of 88.4% and the forced outage rate of only 3.5% during the period reported, is due to the use of main components with high availability and the mature design of the combined-cycle system. The design has been influenced by an analysis of the failures occuring during operation of the previously built Donge combined-cycle plant. It is expected that the availability of the Korneuburg-B plant will in future rise above 90%, as the outage rates caused by some modifications, necessary after commissioning, will no longer effect future time availability. Nevertheless, the forced outage rate of 3.5% represents a very low rate achieved by preventive measures and prompt intervention (13).

The plant has a high number of equivalent life time hours than service hours. The high number of starts of the gas turbine during a consecutive period of 559 days demonstrates that the plant was operated to its uttermost.

The 91% start reliability of the plant can be considered as high. Contained in this figure are all protective shutdowns originated by the plant's automatic control system in order to avoid damage caused by insufficient water levels in the boiler drums, wrong valve positions, etc. 36% of the registered start failures were caused in the steam/water part, 38% by the ignition equipment of the gas turbine (mainly due to the reaction of the flame detector), and 25% in other parts of the gas turbine.

The 100% stand-by capacity of certain important plant components, such as cooling water pumps, condensate pumps, feed water pumps, control valves and the controlled system of fuel supply, instrument and service air, have essentially contributed to achieve availability. With the same object, two out of three circuits of important supervisory control systems, i.e. the flame detector of the combustion chamber and position indication of the damper in the stack, etc. are always ready for emergency purposes.

Automatic supervision

The applied equipment for control and monitoring has demonstrated its absolute reliability. The full automatic process control has essentially simplified the operation and supervision task. To obtain clearance for start-up it is only necessary to give the inputs regarding the water level of the River Danube in the water intake, the pressure in the natural gas supply system and the water levels of the two boiler drums and the feedwater tank. All other start-up processes of the main and auxiliary systems perform automatically in the correct sequence after pushing the start button. The fulfillment of all criteria, which are preconditions for the development of the start-up procedure of the different plant subsystems, is controlled and continually checked step-by-step in order to ensure absolute safety. If the criteria cannot be met (in the case of failure) the respective information is indicated in the control room and at the same time the start-up is stopped.

The level of automation of the push button initiated operation can best be seen in the small personnel requirement. The 125 MW Korneuburg-B combined-cycle plant is operated in two-man shifts for start-up, operation and shutdown. One operator supervises the plant in the control room, the second, in the plant, carries out checks according to instructions given by the first.

Experience with the gas turbine

The gas turboset features exceptionally smooth running characteristics. The values of the amplitudes of the shaft's vibrations, measured in both bearings, are in the range of 0.9 - 10 μm. According to the German standard VDI 2056 these amplitudes are qualified as 'good' - the lower value of 0.9 represents an extremely small rate. The indicated figures correspond to a double amplitute of 0.07 - 0.79 mills.

Though the plant is located in a rural region, 8 km far away from any industry, the blading of the axial compressor has suffered some light corrosion at the blade inlet edges caused by air pollution. This appearance of pitting is to be considered as relatively normal in countries with a wet climate. Since corrosion affects the bending fatigue restistance of the blading material, the blades have been substituted by ones with anti-corrosion coating.

Deformation of the hot-gas casing (the hot gas duct between the vertical combustion chamber and the axial gas turbine inlet) forced the replacement of this component as a preventative measure, by a new casing made from more resistant material. The 982 hour standstill of the plant thus caused was the main incident which affected availability. A forced outage of 129 hours resulted due to failure in the start device. The natural gas fuel containing only traces of harmful substances caused no problems.

The plant owner NEWAG had already decided in the tender stage of the project not to install an air intake filter. The pressure drop normally caused by a filter was thus eliminated and a better efficiency and power output was obtained. The plant owner is still convinced that this decision was right, as the corrosion found on the blades of the compressor would not have been avoided by application of an air intake filter. Compressor fouling is obviously very little so that no loss of power worth mentioning was noted. The gas turbine compressor is washed in a mean interval of approximately three months. The fouling depends on the season and is mainly caused by pollen and insects. The washing method is therefore adapted to this type of fouling. The decrease of output by fouling was never more than 2% in the reported period.

Experience with the steam generator

The many and extremely rapid starts in temperature from ambient up to 500 °C (932 °F) in a time as short as 17 minutes are a very special problem for such a large construction. The heat recovery steam generator withstood the heavy loads without difficulties.

In table D no availability figures are given for the steam generator because the little modifications necessary were all executed together with the regular maintenance work during the planned maintenance outage hours - therefore no detailed reports were available. The availability of the steam generator is at least as good as the 91.5% gas turbine availability. The forced outage rate is zero since the steam generator never caused forced shut downs of the plant.

The omission of a flue gas bypass (because of the reasons mentioned before in the plant description and due to the lack of space) necessitated the design of the steam generator for dry operation, without water in the boiler circuit, at a gas inlet temperature of 491 °C (916 °F) when the gas turbine works at full load. This operation mode is only intended during longer outage of the steam turbine if the power output of the gas turboset is required by the grid. Dry operation was being practised for three days during the acceptance tests. The experience gained with this trial run has demonstrated that the flue gas flow causes a humming noise of very low frequency in the steam generator, so that now NEWAG would prefer to provide future plants with a flue gas bypass.

The silencer between gas turbine and steam generator initially had a low service life due to bad distribution of the hot gas stream. Installation of a flow speed correcting grating and improvement of the sound damping elements eliminated this deficiency.

The superheater of the high pressure boiler is oversized for safety reasons. The maximum admissible live steam temperature for the steam turbine is therefore obtained at an ambient temperature of 21 °C (70 °F). The normally required water injection into the superheater for the limitation of steam temperature was omitted, due to the low annual mean of 500 hours with ambient temperatures over 21 °C. Over temperature of live steam did not force reduction of steam turbine output up till now.

There has been trouble with the expansion joint after the diffuser of the gas turbine. This bellow joint made from lead-asbestos tissue, with mineral wool filling, has to compensate for a thermal expansion of 240 mm. Irregular deformations of the bellow and dislocation of the wool filling were corrected by means of an improved guide device.

The damper in the stack has given very positive results. When the device is closed it avoids cooling down of the water in the steam generator by instreaming air during the daily standstill, thus enabling the time for the start-up to be kept as short as possible. At low ambient temperatures in winter, freezing of water in the systems, which could destroy the heat-recovery steam generator, can be prevented.

No dewpoint corrosion was noticed in the heat exchangers flue gas side. This is the consequence of the very low H_2S content of the natural gas, 30% of which comes from Austria's own resources - the balance, 70%, is imported from Russia.

Experience with the steam turbine

The steam turbine has an outstanding fast start capability. The steam turbineset also runs smoothly. The measured amplitudes of the shaft's vibration, at both bearings are in the range of 1.5 - 3 μm, which are very low and correspond to a double amplitude of 0.12 - 0.24 mills.

An unprevented steam leakage at the flange of the turbine casing will be corrected during the next planned revision. Forced outage of the steam turbine set amouted to 43 hours during the reported period, and were originated by failures occurring in the auxiliary systems, namely at the steam bypass and at the rotor turning gear. No other difficulties appeared. The time availability of 99.7% and the related low forced outage rate of 1.0% demonstrates the reliability of the installed equipment.

Environmental effects

Noise emission. The limit of maximum 60 dBA at the power plant's outer boundary is kept within 6 dBA. Although the noise level is under the limiting value, a high amplitude in the frequency range of 88 - 90 Hz causes annoying vibrations outside the power plant area. These vibrations are probably induced by the flue gas flow in the silencer/steam generator section. The phenomenon is still being investigated.

Chemical emissions. Because of the very low sulphur content in the form of 0.1 - 0.2% H_2S in the natural gas fuel, no inadmissible sulphur compound emissions in the flue gas could be measured.

No legal limitation exists in Austria regarding NO_x. The firing of natural gas in the single combustor does not cause any soot pollution. The burner allows a careful adjustment of the flame in order to give perfect combustion. The flue gas exhaust at the stack outlet is almost invisible during all plant operation conditions.

CONCLUSIONS

Plants based on the combined-cycle principle, exemplarized here by Korneuburg-B, constitute a highly economic possibility for power generation. Low initial investment, high achievable efficiency (low heat rate), rapid start-up and good availability (13) are the advantages.

The operational experience gained with the Korneuburg-B plant has established that with a high degree of automation it is possible to operate a combined-cycle plant with a minimized personnel requirement.

Building of reliable combined cycle plants with trouble-free running after commissioning is now a standard achievement with current technical know-how.

Natural gas for power generation is not always accessible, but where suitable fuels for gas turbines are on hand, responsible bodies should consider combined-cycle power plants for the best fuel economy.

The good utilization of primary energy of combined gas/steam turbine plants may be enhanced to over 80% when the plant is equipped with a co-generation steam turbine, thus producing heat for industrial purposes or public district heating. Depending on the prevailing conditions, the fuel savings so realized reduces essentially the cost of produced energy. (6)

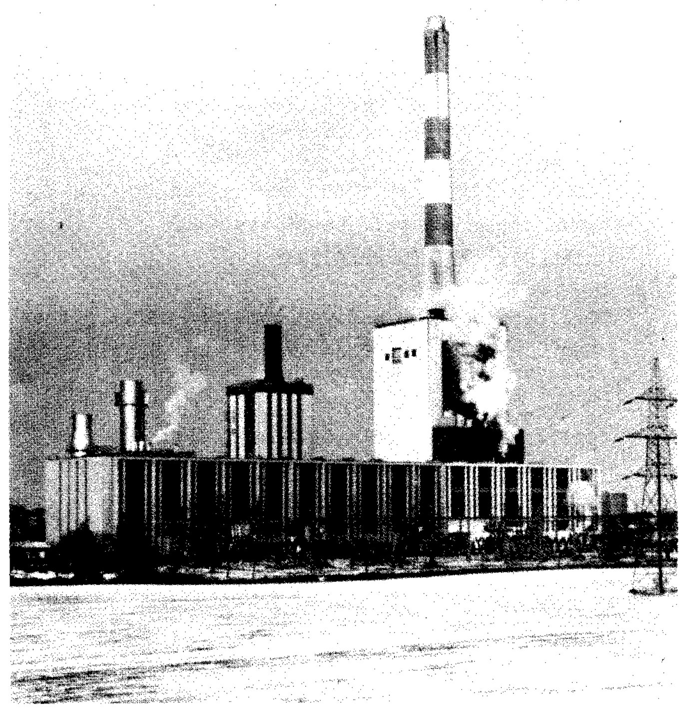


Fig. 16 - The Korneuburg power station:
The 125 MW combined-cycle power plant unit is located on the left side of the building (second stack from left). The station also includes a 77 MW and a 280 MW steam power plant unit.

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