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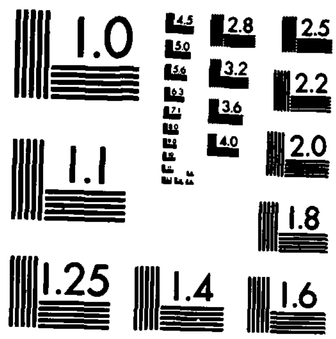


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# FOREIGN TECHNOLOGY DIVISION

GAS TURBINES FOR THE PRODUCTION OF ELECTRICAL AND THERMAL ENERGY

by

V. Potocnik

# EDITED TRANSLATION

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GAS TURBINES FOR THE PRODUCTION OF ELECTRICAL AND THERMAL ENERGY

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Basic types of gas-turbine constructions are described with the most important characteristics. A review is presented of the area of application for gas turbines in the production of electrical and thermal energy, with a limited account of constructions which have been built and the trends in potential development.

## Introduction

Of the four types of prime movers which are being used today in the production of electrical energy (steam, water, and gas turbines and Diesel engines), the gas turbine is displaying a trend for the most rapid expansion. According to data from industrially developed countries, orders for gas turbines in recent years have amounted to about 25% of the total gas-turbine capacity already installed to date. If we take into consideration the fact that the annual increase in installed capacity for the production of electrical power is increasing at a rate of about 7%, then the advancement of gas turbines is evident. In the United States, during the period of 1970-1975, about 6000 MW, or about 15% of the total installed capacity, was due to gas turbines in the total annual increase in capacity installed (about 40,000 MW) [1].

An interesting example is the Public Service Electric and Gas Company of New Jersey, which has installed, in a system of about

8000 MW, about 30% or 2400 MW in gas turbines fueled by diesel or light oil [9]. Annual production of electrical power from the gas turbines amounts to about 7% of total production. Although they were intended for 800 hr/yr of operation, the gas turbines have achieved an average of 2500 hr/yr.

In East Germany, about 1000 MW of gas turbines were ordered in 1970.

In the industrially developed countries, the share of gas turbines in the total installed capacity is rapidly climbing toward 10% or more, while in our country, it is approaching a symbolic 1.5%.

It is worthwhile to mention that previous predictions for the rate of increase for the share of gas-turbine participation have been quite modest.

The expansion of gas turbines in recent years has, on the one hand, made possible refinement of their technical-economic characteristics, which are in very good agreement with the new demands for the production of electrical and thermal power, and on the other hand created a trend toward the use of the so-called pure fuels for protection of the human environment, in particular in towns.

Naturally, we dare not ignore the fact that the steam turbine, and in some countries the water turbine, will always predominate in the production of energy. This is evident from Fig. 1, in which the largest units so far are indicated.

However, while steam turbines have today practically attained a maximum development, and water turbines are limited by the availability of water power, gas turbines are in full development.

## Basic Types and Characteristics of Gas Turbines

The fundamental thermodynamic process of today's gas turbines is the Joule or Brayton process, indicated in ideal form (without loss) on a T-S or thermal diagram (Fig. 2).

Suction of air in a compressor is performed at location 1 (in the position circle) and exhaust of the smoke gases from the gas turbines at position 4.

The thermodynamic level of the operation is given by the expression:

$$\eta_{th} = \frac{\text{useful work}}{\text{heat produced}} = \frac{AL}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

By substituting the corresponding values, we obtain:

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \frac{T_4}{T_3}$$

The temperature $T_4$ is defined by the state of the ambient air. Therefore, the initial temperature of the working substance in the turbine remains the major factor in improving the economic aspects of a turbine construction, which are suitable for all types of gas turbines, as well as for the other types of thermal-powered prime movers.

The basic process is in principle suitable for the 2 main groups of gas turbines used today:

- <u>the open-cycle gas turbines</u>, or internal-combustion turbines, in which the working substance (air - exhaust gases) is continuously renewed, or the fresh working substance (air) is sucked out of the environment and the exhausted working substance (the exhaust gases) is emitted into the environment;

- closed-cycle gas turbines or external-combustion turbines, in which the same working substance (air, He, $CO_2$) is continuously circulated in a circuit. This is a construction similar to that of steam turbines, and these turbines are also called air-source turbines, because air figures as the working substance, while turbines with other fluids are still in the developmental stage.

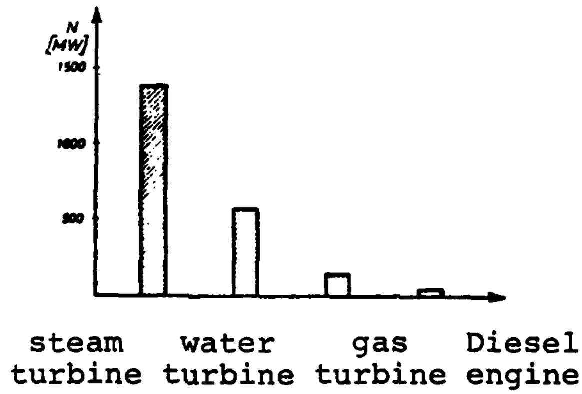



Fig. 1. Maximum capacity of prime movers.

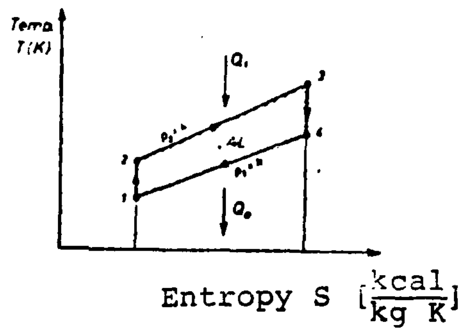



Fig. 2. Basic process of gas turbines
$Q_1$ : heat provided by fuel
$Q_2$ : heat exhausted to environment
1-2: adiabatic compression
2-3: isobaric introduction of heat
3-4: adiabatic expansion
4-1: isobaric exhaust of heat
AL : useful work

Of the devices manufactured today, the most widely represented by far are the open-cycle gas turbines.

One of the most important characteristics of simple gas turbines, from the thermodynamic standpoint, is that they provide a large amount of heat at a relatively high service temperature level, in contrast to steam-turbine devices, in which waste heat occurs at a low temperature level which is practically unusable. This difference is shown in Fig. 3 in the form of a simplified Sankey diagram of energy flow for a simple gas turbine with open cycle and a condensation steam turbine.

Because of these characteristics, waste heat has been used in many types of gas turbines for pre-heating the air for combustion or for the production of steam or water sources, all due to an increase in the device's economy.

Another important characteristic which is associated with open-cycle gas turbines is the large surplus of air for combustion, because this air is also used to cool the exhaust gases upon entering the turbine. Because of this, the gases emitted from the turbine contain large amounts of oxygen (15 to 18%). This fact, associated with the large amount of heat emitted, is utilized in gas-steam devices, which are a combination of gas and steam-turbine devices. Such a combination (combo unit) combines the advantages of gas and steam turbines to a specific degree, so that in recent years, they have been utilized more and more frequently for various purposes.

Of the numerous makes of gas turbine, 4 main types are described in Fig. 4 in tabular form, which appear with specific variations in the greatest number of models.

In comparing gas-turbine devices with steam turbines, the following may be said:

**Advantages**

- low specific investment;

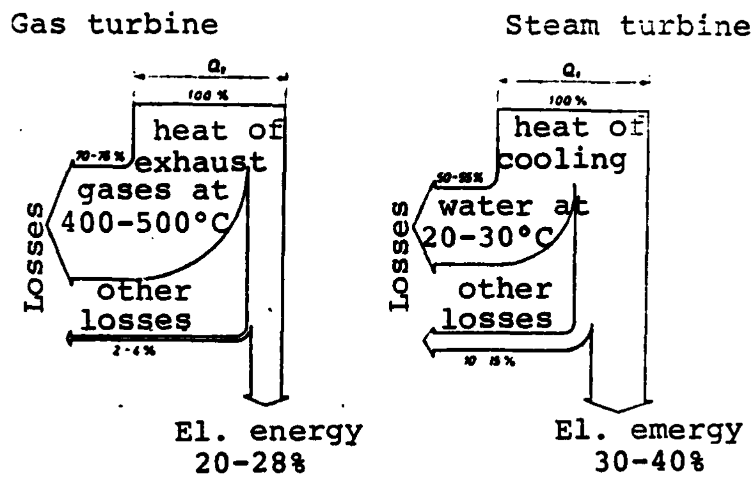



Fig. 3. Energy flow for a simple, open-cycle gas turbine and a condensation steam turbine.

- short construction time (in the US, about 1 year, at the present time);

- considerably fast start:

- far less consumption of cooling water;

- less space needed;

- less pollution of the environment, etc.

Disadvantages are:

- greater cost variability;

- limitations regarding fuel;

- lower unit capacity;

- higher noise level, etc.

The problem of fuel for gas turbines is one of the most important ones operating to limit somewhat the broad application of gas turbines. There is practically no limitation for a closed-cycle turbine, except from the viewpoint of sulfur content.

For open-cycle turbines, it is possible to utilize, without any limitation, gases and light liquid fuels with limited amounts of harmful constituents (vanadium and similar metals and sulfur for devices with the utilization of the heat emitted). Low-quality liquid fuels are also used with adequate fuel preparation (separation and additive supplementation) and decreased initial temperature of the exhaust gases.

Solid fuels in their original form hardly ever are considered for open-cycle turbines.

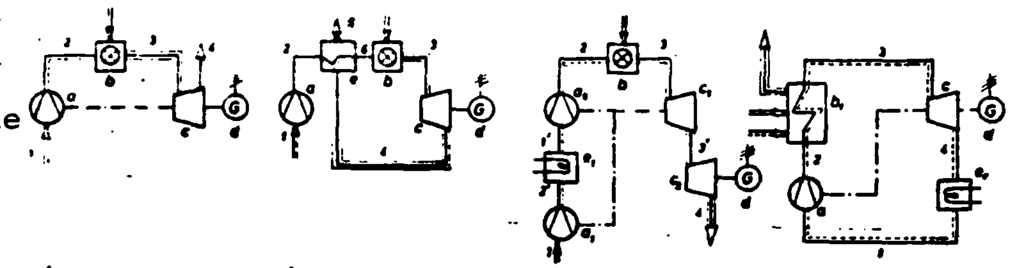
It must be mentioned here that much work is being done in the world on the development of a procedure for improving low-quality liquid and solid fuels in connection with clean-air regulations. This trend is conditioned by the relatively unsuccessful procedure for purifying exhaust gases, which has shown itself to be too expensive in the majority of cases. Among the numerous procedures for improving fuels, we may mention the so-called SGP (Shell Gasification Process), whereby difficultly combustible oil is converted to combustible gas and vapor with solid sulfur as a by-product. Likewise, several procedures have been developed for solid fuel for improving coal, such as the Lurgi process for degasification of coal used at TE Lünen and the so-called SRC process (solvent-refined coal), in which purified coal and sulfur are obtained.

The initial temperature of the exhaust gases for open-cycle gas turbines, as one of the most important factors in the economy of a device, depending on the type of fuel, the purpose, and the materials for high-temperature operation of the turbine, varies today from 650 to 950°C. Experiments are also in progress with

| Type | I | II | III | IV |
|---|---|---|---|---|
| Cycle | Open | Open | Open | Closed |
| Name | Single-axis gas turbine without heat regeneration | Single-axis gas turbine with heat regeneration | Double-axis gas turbine without heat regeneration | Single-axis gas turbine |

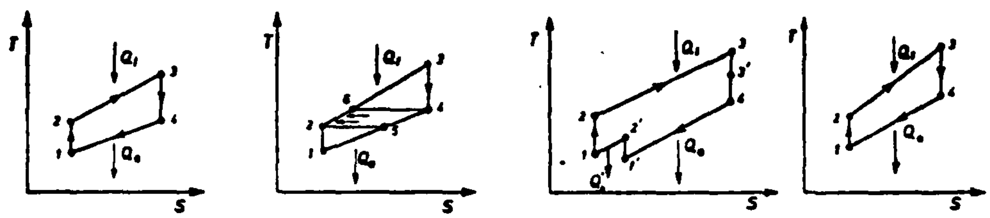
Schematic

a - compressor
b - combustion chamber
c - gas turbine
d - generator
e - heat exchanger



air
fuel
exhaust gases
mechanical linkage

Ideal process



| | I | II | III | IV |
|---|---|---|---|---|
| Unit capacity (MW) | 2-100 | 2-80 | 2-80 | 2-35 |
| Specific heat consumption under compression (kcal/kWh) | 4900-3000 | 3500-2500 | 3400-2400 | 2000-2500 |
| Specific investment (US$/kW) | 200-80 | 250-110 | 230-100 | 380-200 |
| Amount of soda for purge cooling ($m^3$/MWh) | about 5 | about 5 | about 40 | about 100 |
| Time from cold start to full load (min) | 1-10 | 10-30 | 1-10 | 60-90 |
| Limitation with respect to type of fuel | moderate | severe | most severe | minor |

**Fig. 4. Basic types of gas turbine.**

initial temperatures higher than 1000°C.

Area of Application for Gas Turbines in Thermal Power

In Figs. 5 and 6, typical diagrams are shown for the electrical load on a system with 3 main types of load: peak, average, and basic.

It can be said that gas turbines have so far been successfully included in the production of electrical energy for covering peak loads and that it is in the process of being included in the area of average loading. Serious investigative efforts are being made in work on including gas turbines for covering basic loads as well.

Gas turbines have been more and more often utilized in recent times in the area of heating.

An interesting application of gas turbines is in the modernization and expansion of old uneconomical thermoelectric power stations, whereby, in addition to a relatively inexpensive increase in capacity, the economy of the device is considerably improved.

In industrial thermal power, gas turbines are quite frequently utilized. Aside from the area of electrical power production, gas turbines are finding application to the following purposes as well:

- drive systems for ships, aircraft, and vehicles;

- compressor stations for gas pipelines;

- pumping stations for oil pipelines;

- drive systems for auxiliary engines;

- so-called total-energy systems for providing isolated consumers with electrical power, heat, and refrigeration;

- desalinization of seawater, etc.

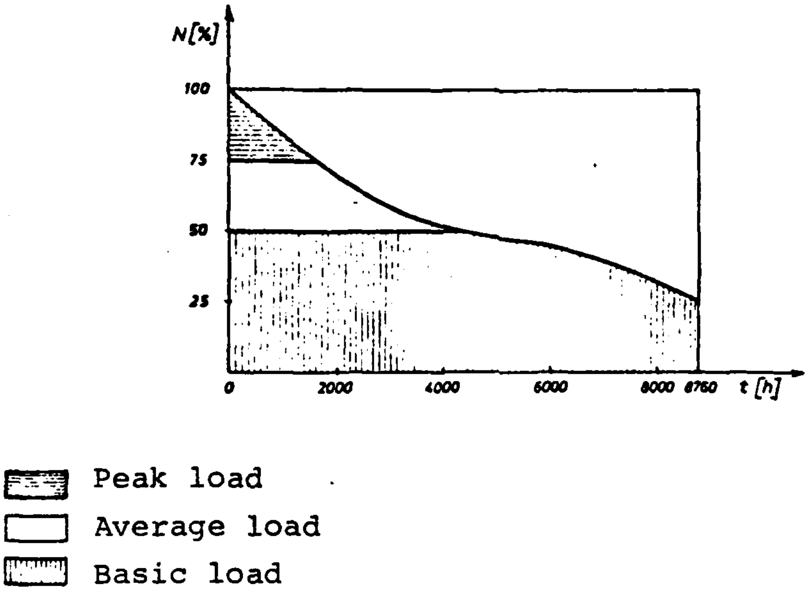



Fig. 5. Typical annual diagram for electrical load.

## Peak Electrical Load

In this group are loads of 500-2000 hours of annual use, depending on the characteristics of the system. They serve to cover seasonal and daily load peaks.

The load range up to 500 hr/yr is often called hyperpeak load.

Thermoelectrical power stations with gas and obsolete steam turbines, as well as accumulation and pump hydroelectric power stations, serve to cover peak loads.

Peak-load units must satisfy the following main conditions, in the general sense:

- capability of a rapid automatic and remote start;

- low investment and maintenance expense;

- high drive arrangement, etc.

Drive expenses, or at the bottom line, the cost of a kilowatt-hour, however, play a secondary role due to the relatively brief annual use.

The conditions cited are also of value potentially for rapid loading (emergency power), which is an especially real problem at consumption centers where large units have turned off or networks have broken down.

Type I or type III gas turbines (with new or auxiliary aviation gas turbines as gas generators as in Fig. 4 correspond very well to all these conditions. Such gas turbines are today offered in a package construction, in order to significantly reduce assembly time and the demand for minimal size area. The noise problems are reduced to a minimum with adequate sound isolation, so that such a device can be located in a city area, as has already been indicated in practice.

Fuels for such turbines, natural gas and high-quality liquid fuel, correspond to the regulations for air purity in cities.

Minimal consumption of cooling water, on the one hand, offers great freedom in the selection of electrical power station locations and on the other hand, leads to minimum thermal pollution.

For these reasons, gas turbines have in the past decade attained complete acceptance in the area of covering peak electrical loads, which may also be concluded in part from the incomplete representation of devices manufactured or under construction (Table 1).

An interesting but as yet unrealized solution in the development is a gas electrical power station with underground accumulation of compressed air to equalize the daily load diagram. In anaogy to a pump hydroelectric power station, in such a device, during the nighttime minimum, the unit accumulates electrical power from the network in the form of compressed air, which is returned to the network during the daytime maximum. This solution promises very satisfactory peak energy values.

Average Electrical Load

Recently, more and more attention has been paid to units for covering average loads (from about 2000 to 4500 hr/yr), which is a problem of passing over the daily load diagram or covering the daily peak loads. Up until recently, the former basic units were used for such loads, which proceed from the new basic units, especially nuclear electrical power stations, in the middle of the diagram for electrical load. Today, it is becoming more and more understandable that a new type of unit is useful for such loads for the following reasons:

- large new basic units display comparatively lower distribution and weak capacity for variable loads;

- the bridges between the daily maximum and minimum load are increasing;

- the unit size of the basic units is increasing in relation to peak load;

- the problem of monitoring load while large units are turned off remains very real.

The requirements set for units to cover average loads are as follows:

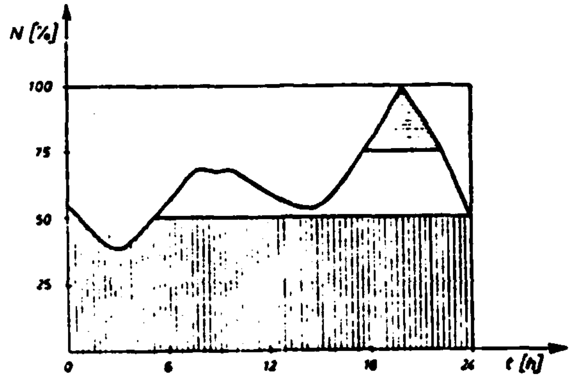



Fig. 6. Typical daily diagram of electrical load.

Table 1. Summary of electrical power stations with gas turbines for covering peak loads.

| Country | Station | Units (MW) | Fuel | Year brought on-line | Remarks |
|---|---|---|---|---|---|
| a | b | c | d | e | f |
| USA | Various | About 50 units, 10-70 MW | Natural gas and various heating oils | 1973-74 | On order from 6/1/71 to 5/31/72 |
| Germany | Berlin-Steglitz | 2 × 25 | Heavy heating oil with additives | 1960 | |
| | Weinfelden | 2 × 11 | " | 1959-60 | |
| | Wedel-Hamburg | 2 × 55,9 | Light oil | 1971 | |
| | Stuttgart: TE Gaisburg | 2 × 57 | Natural gas | 1971 | |
| | TE Münster | 3 × 25 | | 1974 | |
| | Dettingen | 1 × 55,9 | Light oil | 1973 | |
| | Altbach B | 2 × 55,9 | Natural gas and light oil | 1973 | |
| | Wilhelmshaven | 2 × 55,9 | " | 1973 | |
| | Bielefeld | 1 × 55,9 | Light oil | 1974 | |
| | Arndorf | 1 × 87,6 | " | 1974 | |
| Great Britain (about 10 electrical | London: Croydon | 2 × 80 | Diesel oil | 1965 | |

| a | b | c | d | e | f |
|---|---|---|---|---|---|
| power stations) | Wimbledon | Tot. 300 | Light oil | 1974-75 | |
| | Early | 2 × 60 | Diesel oil | | |
| | Letchworth | Tot. 150 | | | |
| | Wattford | Tot. 150 | | | |
| | Leicester | Tot. 150 | | | |
| | Ocker Hill | Tot. 300 | | | |
| Sweden | Västervik | 1 × 43 | Heavy heating oil and distillates | 1959 | |
| | Sundsvall | 1 × 43 | " | 1962 | |
| | Stockholm | 1 × 56 | | 1969 | |
| | Various | 4 × 70 | Heating oil and distillates | 1970-72 | |
| | Oeresund Malmö | 2 × 55.9 | Light oil | 1970-71 | |
| Austria | Beö | 1 × 80 | | 1974 | |
| | Theiss | 1 × 70 | | | |
| Netherlands | Hengelo | 2 × 55 | Natural gas and light oil | 1968 | |
| Belgium | Socolie | 1 × 23 | " | 1969 | Combo unit |
| | Various | 7 × 20 | Distillates | 1967-71 | |
| France | Brest | 1 × 20 | Heavy heating oil | | |
| | | 1 × 82 | Natural gas and light oil | 1974 | |
| Finland | Kellosaari Helsinki | 2 × 55.9 | Light oil | 1972-73 | |
| | Tavastehus | 1 × 50 | Distillates | 1970 | |
| Venezuela | Machado Caracas | 3 × 21 | Natural gas and light oil | 1973 | |
| Kuwait | Shuaiba Nord | 4 × 30 | " | 1969 | |

| a | b | c | d | e | f |
|---|---|---|---|---|---|
| Australia | Dry Creek | 3 X 75 | | | |
| | Various | 2 X 30 & 1 X 60 | Diesel oil | 1968-70 | |
| Romania | Bucharest | 3 X 34 | Natural gas and distillates | 1968 | |
| Hungary | Budapest | 2 X 27.6 | " | 1972 | |
| Italy | Rome | 1 X 22.3 | Distillates | 1968 | |
| | Chivasso | 1 X 30 | Distillates and oil | 1962 | |
| Argentina | Buenos Aires | 1 X 27.6<br>14 X 16.2 | Natural gas and distillates | 1968-72 | |
| Greece | Crete | 2 X 15 | | 1974 | |

- capacity for rapid variation in load;

- rapid and inexpensive daily starts;

- capacity for remote and rapid start;

- minimum of operational personnel;

- short construction time;

- relatively low investment costs as well as moderate running costs;

- good behavior under partial load;

- high availability.

One of the optimal solutions corresponding to a majority of the requirements mentioned is a combined gas-steam device (combo unit) of specified manufacture. In addition to fulfilling these requirements, such a device even has those characteristics which provide operations which are attractive for average loading:

- the possibility of putting the gas turbines into operation significantly surpasses that of the entire device;

- the gas and steam turbine can be operated independently, so that repair of the device need not mean loss of operation by the entire unit.

Combo units can be divided into 2 main groups of product:

1) a gas-steam unit, in which a gas turbine is included in front of a steam-turbine device; the exhaust gases from the gas turbine are about 400-500°C exiting at the steam boiler, whereby oxygen is obtained for burning additional fuel, as well as waste heat; supplemental heating in the steam boiler may vary from 0% (pure exhaust boilers) to 100%, depending on the oxygen available; at 100% additional heating, the ratio of power for the gas-turbine and steam-turbine units is about 1:5 and the ratio of fuel burned in the gas turbine and by the steam boiler is about 1:3;

2) a steam-gas unit, in which a gas turbine is included behind a steam boiler (a so-called pre-condenser boiler of the Velox type); fuel combustion is performed in only one place - in the steam boiler; waste gases from the steam boiler go into the gas turbine.

Mainly because of construction problems with the manufacture of a pre-condenser boiler at high pressure on the part of exhaust gases and drive flexibility, a product of type a) or the gas-steam unit is used today for the majority of high power units.

The principal scheme for a gas-steam unit is shown in Fig. 7; the corresponding process is shown in a thermal diagram on Fig. 8.

The fluid states for the gas process are designated in Figs. 7 and 8 by the numbers 1 to 7, while the fluid states for both figures are designated by the letters A to G.

Such a solution for a combo unit is the combination of open-cycle single-axis gas turbines of type I in Fig. 4 and a steam unit with or without a single intermediate heating of the steam.

With this combination, economical solutions are attained for a unit in comparison with a pure steam unit, which is evident in the favorable price of electrical power as a result of lower specific investment and lower operating costs, depending on the manufacture of the combo unit.

The economy of such devices in covering average loads in comparison with steam units leads precisely to the expression, when the average annual specific consumption of heat is taken into consideration, in which the following factors have an effect, in addition to the heat consumption at the generator terminals in an optimum operating regime:

- heat losses in starting and stopping the unit, which are closely associated with the duration of a hot or cold start;

- the path of curvature for specific heat consumption at different loadings;

- the particular electrical consumption of the electric power station.

In all of these factors, the combo unit displays an advantage over a steam-turbine unit.

One of the advantages of the combo unit over a steam unit is that upon starting, much less power is used (about 1.5 MW for a 320-MW unit compared with 6-10 MW for a comparable steam unit).

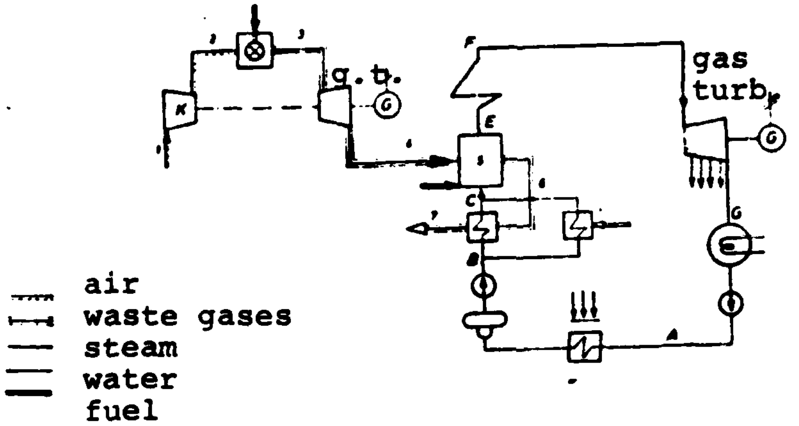



Fig. 7. Principal scheme for a gas-steam unit.

Today there are in operation or under construction a whole series of combo units. It is interesting to mention that in East Germany, during the period of 1972-74, out of about 25,000 MW of installed power in new units, combo units provided about 4500 MW, which, in relation to liquid and gas fuel units and thermal electrical power stations (about 8500 MW), represented about 55% of the total power of new units.

In 1970, combo units in East Germany provided about 10% of the total installed power (51 GW), and it is expected that in 1980 this share may amount to more than 30%. In North America, it is expected that the share of combo units will in the near future amount to 20-30% of total installed capacity.

Practically speaking, all the major manufacturers of gas turbines are able to offer and manufacture combo units with a wide power range.

A summary of the most significant combo units for average loads is given in Table 2.

Basic Electrical Load

In this loading range, which goes beyond about 4500 hours of annual use at full commitment, gas turbines have not been seriously considered up to now, although for small systems, in which gas turbines of types II and III in Fig. 4 are used, a combo unit may show itself to advantage. The TE Emden example in East Germany is interesting, in which a combo unit was put into operation in 1972 with a capacity of 342 MW (54-MW gas turbine and 288-MW steam turbine), with a specific heat consumption of 1990 kcal/kWh in its optimum regime, designed for basic loading at 7000 hr/yr.

In the industrialized countries of the world, significant investigations and experimental efforts are being undertaken on the application of closed-cycle gas turbines in nuclear power plants with gas-cooled reactors. Work on helium or $CO_2$ gas turbines with capacities of up to 1000 MW is becoming greater. Experimental and prototype devices with lower power are now in progress.

Modernization of Obsolete Steam Thermoelectric Power Stations

Because of their lack of economy and their high operating costs, obsolete steam thermoelectric power stations are used less and less in systems, taking on a comparable role as reserves in systems, for example, which cover peak loads, etc. The steam units in such electrical power stations are not the most advantageous for these purposes with respect to their technical characteristics. By the addition of a gas-turbine device of type I or II (with exhaust boiler) to the existing steam-turbine device, a combo unit is obtained at a relatively low investment. Thus the capacity of an electrical power station is increased, on the one hand, and the economy and flexibility of the power station is raised substantially, on the other hand. Such a unit can, in combined operation, achieve all the advantages previously described for large combo units, as well as a specific heat consumption of about 2400 kcal/kWh, so that it may be efficient to include them for covering peak loads.

Furthermore, in this way, the role of obsolete electrical power stations is improved and their lifetime prolonged.

In our country, such assemblies are being planned at the Brestanica and Jertovec thermoelectric power stations.

Thermoelectric Power and Heating Plants

Several things are conditioned upon the fact that the gas turbine has in recent years been more and more accepted for the combined production of electrical and heating power for warming cities. These facts are:

- a large amount of waste heat from the gas turbines, at a relatively high temperature, is available for heating purposes;

- a gas turbine can attain high electrical heating characteristics, such as the proportion of an installed electrical and heating plant (kWh/Gcal):

- the production of electrical power is independent of the production of thermal power and vice versa, which is not the case, for example, for a backpressure steam turbine;

- regulations for air purity in the cities are limiting the use of "unclean" fuels more and more (coal, oil) in heating plants, which makes possible the undisturbed application of gas turbines;

- a gas turbine with a short starting-up period can also serve simultaneously for covering peak and emergency loads.

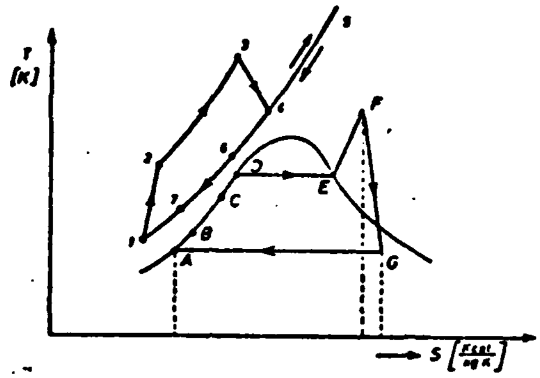



Fig. 8. Gas-steam process for Fig. 7 indicated in a thermal diagram.

Table 2. Summary of electrical power stations with combined gas-steam units for average loads.

| Country<br>a | Station<br>b | Capacity (MW: Gas+ steam = tot.)<br>c | Fuel<br>d | Year put into operation<br>e | Notes<br>f |
|---|---|---|---|---|---|
| USA | Horseshoe Lake | 25 + 235 = 260 | | 1973 | |
| | Lake Nasworthy | 31 + 99 = 130 | Natural gas | 1965-66 | |
| | Various | 12 units 140-600 MW tot. cap. 4150 MW | | 1973-75 | |
| East Germany | Emsland (3 units) | 57 + 400 = 475 | Natural gas and light oil | 1970-72 | |
| | Altbach | 50 + 200 = 250 | " | 1972 | |
| | Gersteinwerk (4 units) | 80 + 320 = 400 | Natural gas | 1972-74 | |
| | Gebersdorf | 55 + 370 = 425 | | 1973 | |
| | Mainz | 50 + 270 = 320 | | 1972 | |
| | Brunsbüttel | 240 | | | |

| a | b | c | d | e | f |
|---|---|---|---|---|---|
| | Marbach | 55 + 250 = 305 | Natural gas and oil | 1973 | |
| | Marl | 134 | | 1973 | |
| | Wilhelmshaven | 53 + 400 = 453 | " | 1973 | |
| | Welcheim | 60 + 310 = 370 | | 1974 | |
| | Lingen (2 units) | 50 + 350 = 400 | | | |
| | Lausward | 2 × 60 + 300 = 420 | Light oil | 1974-76 | |
| | Kellermann (Lünen) | 74 + 96 = 170 | Dissemin. hard coal | 1972 | Gas-steam unit |
| France | Vitry-sur-Seine (2 units) | 45 + 280 = 325 | Coal and natural gas | 1970-71 | |
| | Les Houillères du Bassin de Lorraine | 3 × 16,5 + + 293,5 = 343 | | | |
| Austria* | Korneuburg | 2 × 25 + 25,7 = 75,7 | | 1960-61 | |
| | Hohe Wand | 12 + 68 = 80 | | 1964-65 | |
| Netherlands | Amercentrale | 15 + 390 = 405 | | 1972 | |
| USSR | Nevoinomiska | 50 + 150 = 200 | Natural gas and light oil | 1973 | Gas-steam unit |

With respect to heating, there are open-cycle gas turbines of types II and III as in Fig. 4 (with an exhaust boiler instead of pre-heating the air), closed-cycle ones (type IV), and combo units.

As with obsolete thermoelectric power stations, modernization is possible for old steam units or source-water boilers in heating plants, whereby, in addition to a increase in operational economy, a flexible unit is obtained for peak and emergency electrical load.

In Table 3 a limited summary is presented of heating plants

[*Translator's Note: This was erroneously given as Australia in the original.]

with gas-turbines assemblies.

As is seen from the data presented, the electrical heating characteristics for the gas turbines manufactured are within limits of 500-800 kWh/Gcal.

By way of comparison, we present the electrical characteristics for two heating plants in Zagreb:

- the Zagreb II TE-TO with two condensation-withdrawal steam turbines at 32 MW capacity: about 400 kWh/Gcal;

- the Zagreb I EL-TO with a single backpressure-withdrawal steam turbine of 12 MW: about 250 kWh/Gcal.

Furthermore, with a gas turbine, it is possible to produce 2 or more times the amount of electrical power for a given amount of thermal power.

Industrial Power Stations

Since need exists in industrial power stations in the majority of cases for both electrical energy and thermal power (steam, water sources) for technological and heating purposes, the application of gas turbines is justified by similar arguments as for thermoelectric and heating plants. In addition, in industrial power stations, there are additional times which are corresponding more and more to the supplementation of gas turbines:

- the propotion of use for electrical and thermal power for various industries is in a wide range, which can be covered successfully by various gas-turbine products;

- waste gas from the processing (refinery, coking, high furnace, etc.) is frequently available to industrial power plants,

Table 3. Summary of thermoelectric and heating plants with gas turbines.

| Country | Plant | Gas turb. capacity MW | Gas turb. capacity Gcal/hr | Product | Fuel | Year put into operation |
|---|---|---|---|---|---|---|
| East Germany | Oberhausen | 12.5 | 17/24 | Closed-cycle 1-axis | Hard coal | 1960 |
| | Vahr-Bremen | 2 × 25 | 2 × 30/47.5 | Open-cycle 2-axis | Heavy heating oil | 1959-60 |
| | Sendling München | 2 × 25/32 | 2 × 48/70 | Open-cycle 1-axis | Natural gas and light oil | 1962-64 |
| | Nord Braunschweig | 25/32 | 48/70 | | | 1963 |
| | Freimann München | 2 × 83 | | | | 1974-75 |
| | Flingern Düsseldorf | 80<br>2 × 60 | | Open-cycle with avio-gas turb. | | |
| | Oberhausen | 50 | | Closed cycle with helium | | 1974-75 |
| USSR | Moscow | 10 | | Closed cycle | and light oil* | 1962 |
| | Kharkov | 50 | | Open-cycle | | 1963 |
| | Krasnodar | 100 | | Open-cycle | | |
| | Novyi Salavat (Siberia) | 200 | | Combo unit 40+140 MW | Dissemin. heavy heat. oil from $H_2SO_4$ production | |
| Sweden | Nyhamn | 45 | | | | |
| Austria | Spittelau Beč | 2 × 25/30 | 2 × 50 | Closed cycle | Heavy heat. oil | 1971-72 |
| Yugoslavia | Novi Beograd | 3 × 35 | 3X46.5 with add. heating 3 X 68.5 | Open-cycle 2-axis | Natural distill., heavy heat. oil | 1967 |

*[Translator's Note: The first part of this category was omitted in the original.]

which is suitable for burning in a gas-turbine device;

- the investment for industrial power stations must be as low as possible· therefore, it may be very good to use a gas turbine here, etc.

As an illustration of the frequency of gas turbines in industrial power, we found that one worldwide firm (General Electric) alone delivered about 125 gas turbines with various capacities in 1970 for the production of electrical power in industry.

Gas turbines of the open-cycle types I and II or combined gas-steam devices (usually a single-axis gas turbine and a backpressure steam turbine) are used mainly at industrial power plants.

Gas turbines are not newcomers in industrial power, because they began to be used in this area as long ago as 15-20 years.

Of the numerous types of industrial devices in which gas turbines have been accepted as prime movers, we may count the following:

- the chemical and petroleum industries;

- refineries;

- foundries and steel mills;

- coking plants;

- the paper industry;

- cement plants;

- the tobacco industry, etc.

In Table 4, a limited summary is presented of the significant industrial power plants.

Conclusion

Gas turbines, of all the prime movers, have recently been displaying the most rapid developmental trends and application to the production of electrical and thermal energy. This may be clarified by the following characteristics of gas-turbine devices:

- the simplicity of the product;
- low investment;
- short construction time;
- rapid automatic start;
- variety of application;
- low consumption of cooling water;
- minimum harmful effect on the environment;
- freedom in choice of location, etc.

With the units attained so far with capacities up to 100 MW in a simple product or up to 600 MW in a product combined with a steam-turbine device, gas turbines have been tested to some degree or other in all areas of electrical and thermal power production. In the peak and emergency electrical-load range, gas turbines are dominant. In the area of average electrical loads, in combination with steam turbines (combo units), gas turbines are being used more and more. In the area of thermoelectric and heating plants and industrial power stations, gas turbines are a serious competitor to steam. For basic

Table 4. Summary of industrial power stations with gas turbines.

| Location | Type of industry | Type of gas turbine | Capacity, MW | Fuel | Year put into operation |
|---|---|---|---|---|---|
| Dudalange | Steel | Open-cycle - combo unit | 5.4-13.3 | | 1951-56 |
| Cornigliano, Italy | " | Open-cycle | 16 | | 1961-62 |
| Donawitz, Austria | " | Combo unit | 1 + 14 | | |
| Freeport, USA | Chemical | " | 2 units, 32 + 50; 1 unit, 43 + 20 | | |
| Ferrera, Italy | Refinery | Open-cycle | 2 X 9.5 | | 1964 |
| Tavaux, France | | Combo unit | 15 + 3 | | |

electrical loads, gas turbines have not yet found a place, although for small systems, in connection with nuclear power, their acceptance may be expected in this area.

## LITERATURE


1. *Annual Plant Design Report*, Power 116 (1972), Nov., S-2 do S-24.
2. Gašparović N., *Gasturbinen*, VDI Verlag 1967.
3. Schroder K., *Grosse Dampfkraftwerke*, Bd. 2, 1962, Bd. 3. Teil B, 1968., Springer Verlag.
4. *Ponude za blok 320 MW*.
5. Grupa autora, *Sudovije i stacionarnije gazoturbinije ustanovki zakritovo cikla*, Izdateljstvo »Sudostrojenije«, Leningrad 1971.
6. Časopisi BWK, Power, Archiv für Energiewirtschaft, Energie, Wärme, Tjeploenergetika, Tjeplovije elektrostanciji itd.
7. *Materijali s 8. svjetske konferencije o energiji*, Bukurešt 1971.
8. *Materijali s 2. G. E. europskog kongresa o plinskim turbinama*, Palma de Mallorca 1970.
9. *Diesel and Gas Turbine Progress Worldwide*, Vol IV (1970) № 5 6.

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