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THE PGT2, A NEW 2-MW CLASS EFFICIENT GAS TURBINE APPLICATIONS AND OPERATING EXPERIENCE IN COGENERATION

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BREAK

ABSTRACT

The PGT2 is a single-shaft gas turbine with a 2 MW ISO electric output that, after an extensive factory development program has been launched into industrial service with a number of cogeneration applications in small-medium size industries. The two-stage high pressure ratio compressor combined with the single-can combustor and the two-stage air-cooled transonic turbine provides a compact and rugged architecture. The turbine inlet temperature in the 1050-1100 °C class and the 12.5:1 pressure ratio provide a 25% electrical efficiency and a high exhaust temperature that make this machine attractive for a variety of both civil and industrial applications like hospitals and pulp and paper mills, textile, tiles, cement, glass and food production. The exhaust heat recovery boiler can be either a commercial unit or compact once-through type of proprietary design that is housed in a vertical exhaust duct to substantially reduce powerplant footprint area when space is limited.
The first application that has provided the most extensive operating experience so far is cogeneration in a paper mill in central Italy. Detailed studies on the potential energy saving and on the return of investment cycle were made in collaboration with the client, and provided a valuable basis for further studies that led to additional orders for paper mills, textile and tile industries. The first installed unit is a package comprising a once-through-flow boiler that was full-load tested at the factory before shipping. Commissioning of the cogeneration plant was started in 30 days after shipment and the plant was taken over by the client in less than three months. A dedicated telephone line allows the power plant to be monitored directly from Florence, thus making it possible to gather operational data in real time and to provide this first customer with prompt assistance during the 4-year service and maintenance contract period.
This paper describes the PGT2 design and performance features, the technical and economic evaluations made for the first application, the cogeneration plant layout and a summary of the most significant operational data collected in the initial months of regular service in the paper mill.

INTRODUCTION

The PGT2 (figure 1) is a compact single-shaft gas turbine designed for 2 MW continuous electric output in ISO conditions utilizing both natural gas as well as liquid fuels. Although the performance and the thermal cycle parameters are best suited for applications in industrial and civil cogeneration, it can be used for stand-by and emergency power generation as well. Before starting its development, a comprehensive survey of cogeneration needs was conducted in a variety of small-

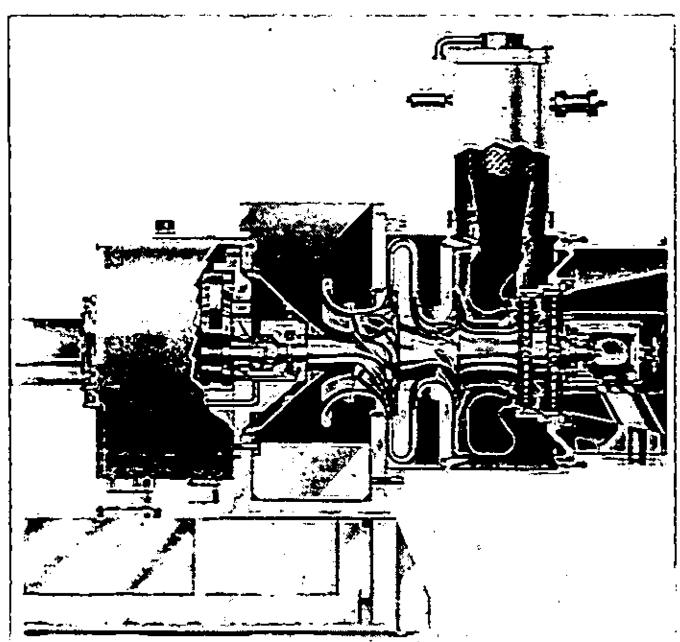

Figure1 PGT2 Gas Turbine Assembly

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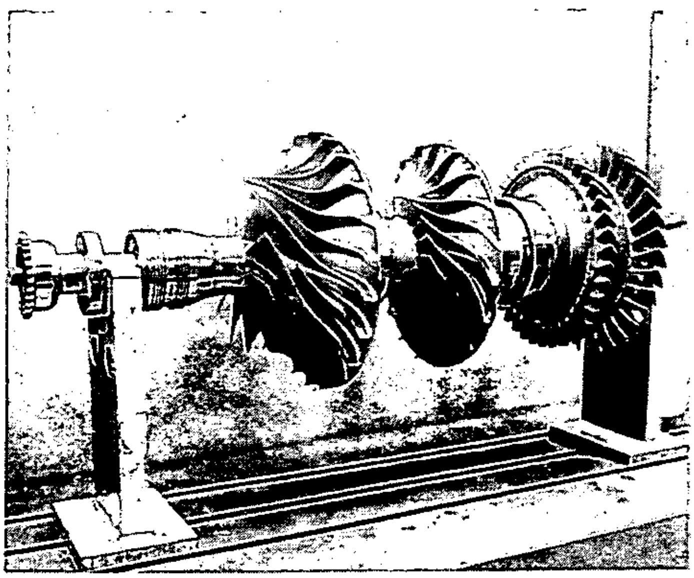

Figure 2 PGT2 Rotor Assembly

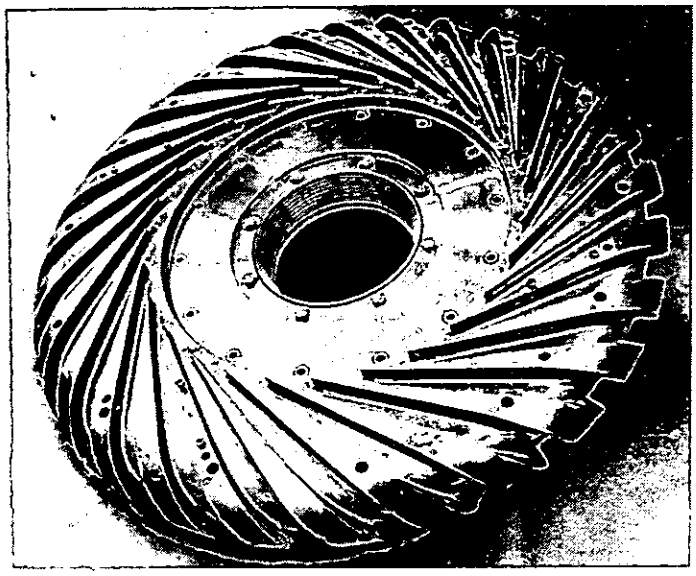

Figure 3 Compressor First Stage Diffuser

medium size Italian industries dealing with textile, cement, tile and paper production (Benvenuti and Stecco, 1989).The survey showed a remarkable potential market in the 1.5-2 MW electric power range, with a preference for supply of high temperature exhaust heat for direct utilization in processes like tile brick and cement production.

The general design concept was oriented towards the area of the heavy duty industrial turbine technology to share most of the Company's experience on larger power machines. One of the principal design goals was to keep the number of parts to a minimum to limit production costs and to simplify maintenance, while assuring the same reliability levels of larger power machines.The centrifugal compressor and the axial turbine design with only two stages each, together with the single can combustor were the milestones to achieve these targets. To conjugate simplicity with competitive performance, technology features typical of larger state-of-art gas turbines were utilized, like the high pressure ratio and a firing temperature in the 1050-1100 °C range associated with turbine blade cooling.

A successful market penetration strategy for a small power machine like the PGT2 must be based on selling standardized modular packaged units with installation and commissioning times kept to a minimum, together with extremely reduced needs for skilled assistance in the after-market period. To minimize risks, the market launch was scheduled a considerable time after the first running prototype became available for testing. During this time, two pre-production units were used in succession for electricity generation at the Nuovo Pignone Florence plant. The machines were operated cyclically with daily startups and shutdowns and in 24-hour service over extended periods of time as well. This extended semi-commercial operation made it possible to debug not only the gas turbine flange-to-flange module, but also, and perhaps principally, all the critical accessories and subassemblies supplied by external vendors, that play a major role in terms of general powerplant reliability and availability.

In 1994 the Company decided to start commercialization with a limited number of units directly packaged at the manufacturing plant and sold to selected customers for cogeneration in representative industrial processes. In the future the gas turbine will be made available to external packagers who will deal with the market directly.

THE PGT2 GAS TURBINE

The 12.5:1 pressure ratio two-stage centrifugal compressor (figure 2) was developed specifically for this gas turbine taking advantage of vast in-house experience on high performance industrial compressor design. The first stage has a transonic impeller providing a 5.5:1 pressure ratio, designed with the use of advanced 3D CFD codes (Benvenuti and Stecco, 1989). The pressure ratio split between the stages was selected to achieve tip speeds suitable for use of 17-4 PH (17% Cr, 4% Ni) and M-152 (12% Cr, 2.5% Ni) steels for the first and second stage impellers respectively. The two stages are provided with wedge-type vaned diffusers, that were matched to the impeller exit conditions through an extensive rig testing program. Of particular interest is the first stage diffuser (figure 3) with vanes extending continuously from the impeller exit through the interstage crossover bend and the return channel upstream of the second stage. The careful diffuser matching associated with the advanced aerodynamic design and the tight impeller-shroud running clearances assured by shroud abradable linings lead to a remarkable 85% overall compressor polytropic efficiency.

The two-stage axial turbine has non shrouded rotor blades, made with Inconel 792, while Inconel 718 is used for both discs. The first stage blades are air cooled to operate with a nozzle exit total temperature ("firing" temperature) of 1060 °C (1940°F). On the initial production machines the cooling system consists of a classical "thermosyphon" layout with longitudinal holes extending from the root bottom to the airfoil tip. However, a more advanced cooling scheme is available for implementation on future units, after general operational experience will have been collected on a number of initial units. It consists of a three-pass cooling air flowpath inside the airfoil (figure 4) with a little air discharged at the blade tip and most through the trailing edge holes. Turbulence promoters inside the serpentine flowpath increase the internal heat exchange coefficients. The considerably higher cooling effectiveness over that of the thermosyphon system is capable of cutting the cooling air flow up to as much as 50% for the same metal temperature, with a 2.5% increase in cycle efficiency and over 3% in output power. A limited number of pre-production cored blades

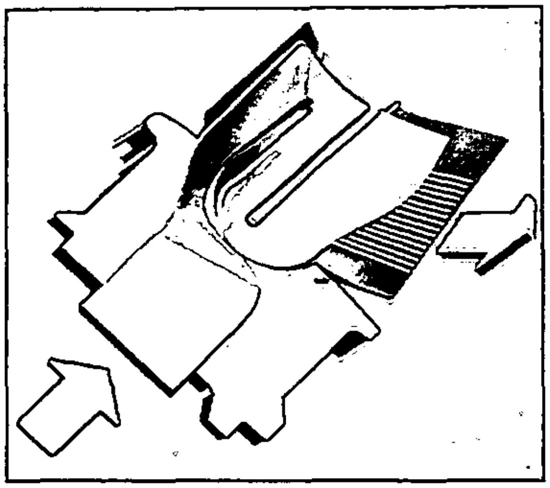

Figure 4 Turbine First Stage Blade Core Layout

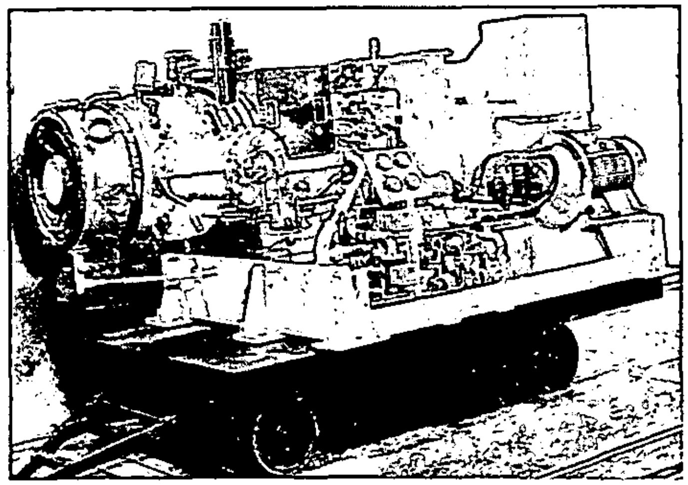

Figure 5 Complete Gas Turbine-Generator Set

were tested on the prototype units in a "rainbow" arrangement with the conventionally cooled blades, and a very useful background on reliabilty and cooling performance was obtained.

The single can combustor, scaled down from larger Nuovo Pignone gas turbine models, can be supplied in the standard configuration with steam or water injection for emission control, as well in the Dry Low NOx version. With the standard combustor, dual fuel capability can be provided as on larger power models. The 22,500 RPM shaft speed is reduced to 1500 or 1800 RPM by a coaxial compound gearbox, that is flanged on the compressor inlet plenum structure supporting the rest of the machine. This assembly and the electric generator are installed on a common baseplate together with the main accessories and auxiliaries (figure 5) which are all easily accessible.

The principal performance characteristics of the gas turbine-generator package are the following, in ISO conditions, with natural gas fuel and a standard electric generator:

Electric Output, KW	2000
Net Heat Rate, KJ/KWh	14400
Net Electrical Efficiency, %	25.0
Exhaust Temperature, °C	525
Exhaust Mass Flow, Kg/sec	10.7

Performance vs. ambient temperature is shown in fig. 6.

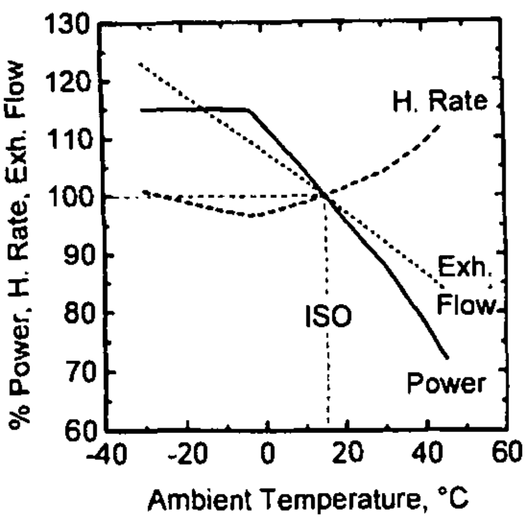

Figure 6 Gas Turbine Performance

THE PGT2 COGENERATION POWERPLANT

The axial exhaust allows easy connection to many types of commrcial steam generators. A proprietary design compact, once-through flow type steam generator (figure 7) is also available when installation footprint area is at a premium. This technology was developed years

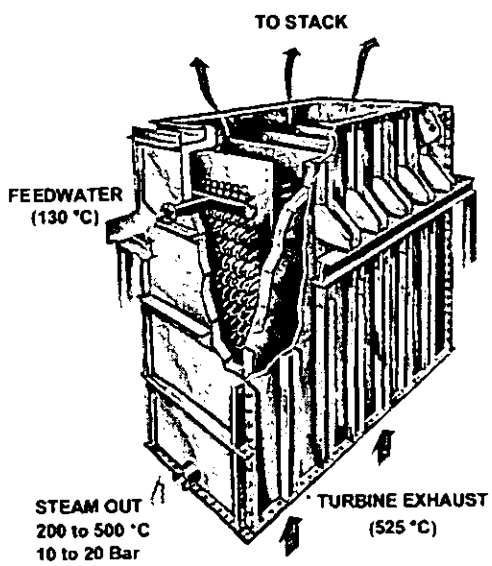

Figure 7 Pignone Once-Through Steam Generator

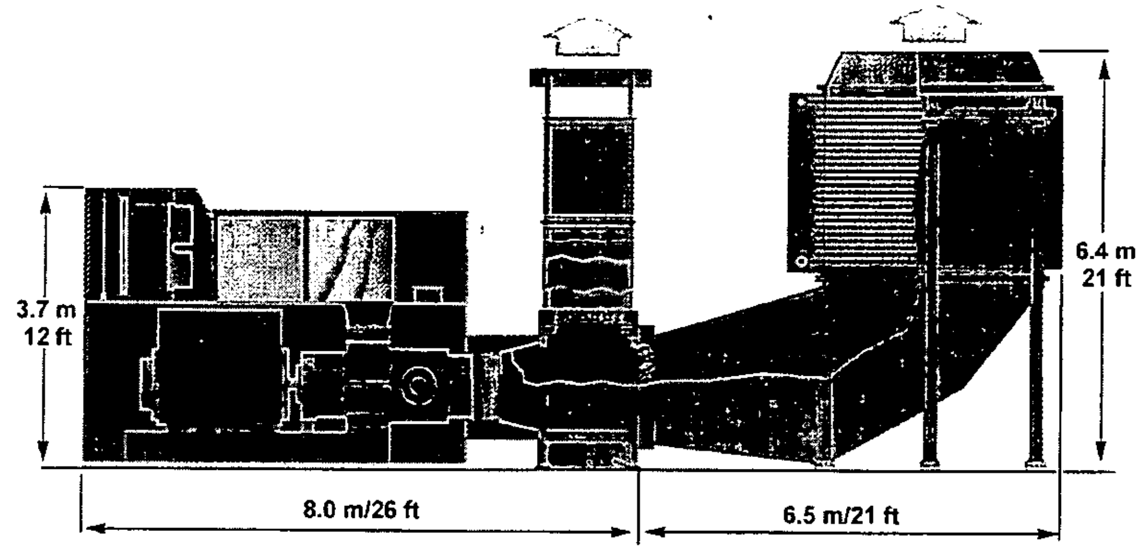

Figure 8 PGT2 Gas Turbine Plant layout with Once-Through Heat Recovery Steam Generator

ago to make available very compact steam generators to be fitted directly into the gas turbine exhaust stack. The once-through concept, besides responding to this requirement, has several advantages with respect to conventional steam generators. For cogeneration applications with frequent startups and shutdowns, the low inertia due to the very small volume of contained water greatly improves operational flexibilty. The absence of a blow-down line, steam drum and recirculation pumps with related accessories, means lower installation costs and improved reliability due to the reduced number of auxiliaries. One disadvantage may be the need for a better feed-water treatment. This need may not be an additional requirement however, if treated water is used for injection into the gas turbine combustor for emission control. The operating and performance data shown in fig. 7 represent the range within which the actual figures can be selected depending on the individual cogeneration or combined cycle requirements.

The first unit of this type was installed on an LM2500 aeroderivative gas turbine driving a gas compressor in a pipeline station (Cocchi et al.,1987). The steam is used in a steam turbine driving an additional gas compressor to boost station flow, thus increasing overall station efficiency. Another steam generator is installed on a Nuovo Pignone PGT5 5 MW gas turbine in a combined cycle for electricity and hot water production for the Florence manufacturing plant (Bianchi and Pucci, 1991). When needed, 50 bar, 450 °C steam is used to drive steam turbines on the process centrifugal and axial compressor production test stands, with a substantial saving in time and cost with respect to utilization of the existing conventional steam generators.

Fig. 8 shows an outline of a complete PGT2 based heat and power generation plant with the once-through-flow steam generator. The total length including the space for the intermediate diverter and bypass stack, does not exceed 15 m/50 ft.

APPLICATION IN A PAPER MILL COGENERATION SYSTEM

Process Requirements

Paper production is a process that requires great quantities of electricity, steam and hot air for paper drying. The process is continuous and the demand for the three types of energy is practically constant and simultaneous. These conditions are ideal for cogeneration with a gas turbine. With respect to the reciprocating engine, the gas turbine has the advantage of providing all of the heat at high temperature, as is required in the paper mill processes. This maximizes the utilization of exhaust heat, and reduces the total energy costs, a key factor in the final product cost.

Technical Evaluations and Economic Study

The first cogeneration contract involving the PGT2 gas turbine was signed with Cartiere Fornai SpA, a paper mill located 80 Km north-west of Rome, with a production of around 100 tons/day of medium and fluting paper for corrugator mills. The production covers 8000 hours/year, with an average electric power demand of 1600 KW and use of 9.5 tons/hour of 12 bar, 200 °C steam. Before installation of cogeneration, steam was produced by means of fuel oil, and the total energy cost accounted for 30.4% of the product cost.

To get the client's acceptance of a gas turbine based cogen plant, the following requirements and guarantees were agreed upon:

- Very high reliability and operational flexibility, to avoid interferences with the production process
- Unattended operation for cost reduction
- Compatibility with Italian laws concerning emissions and noise. This

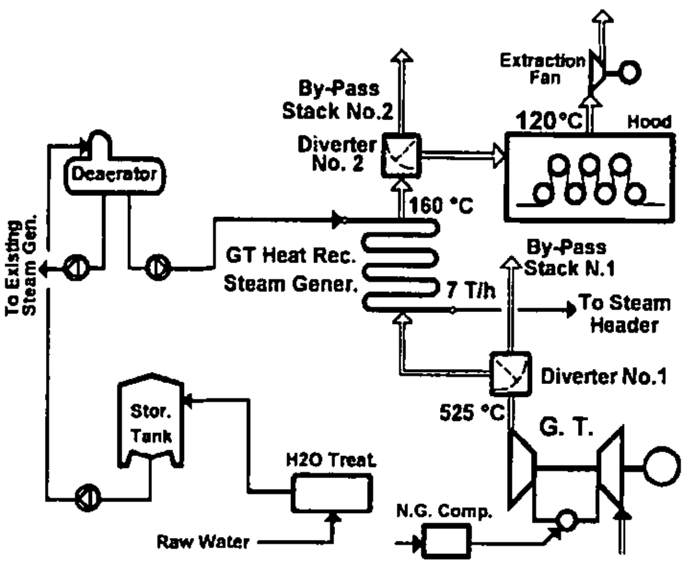

Figure 9 Gas Turbine Cogeneration Plant Scheme

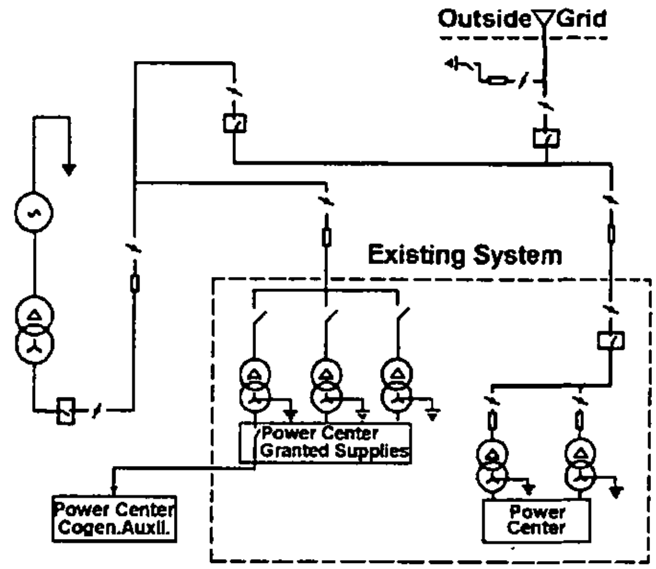

Figure 10 Simplified Electric System Grid

called for a limitation to 100 mg/Nm³ NOx and CO referred to 15% oxygen (dry) in the exhaust, to be achieved with water injection in the gas turbine combustor.

-Small sizes to fit in the existing plant and building space
-Maximum recovery of the consumed fuel energy
-Turn-key supply of the complete system
-Contract for maintenance and remote surveillance.

The nominal 2 MW rating of the PGT2 resulted adequate for providing the 1.6 MW average power, with sufficient margin for peak demand at high ambient temperatures. Before taking the ultimate decision, an accurate economic analysis was performed jointly with the client. The principal economic indexes resulted as follows:

-Discounted Pay-Back time:	3.1 years
-Net Present Value/Investment	2.5
-Internal Return Rate	33%
-Energy Cost Saving	29.7%

These figures showed that the gas turbine is a very competitive alternative to the reciprocating engine, despite the lower electrical efficiency and higher initial investment cost. In fact, the energy saving associated with the larger production of high temperature heat as needed in a paper mill substantially reduces the Pay-Back time and maximizes the NPV. Another aspect in favour of the gas turbine were the maintenance and operation costs that proved to be around one third of those evaluated for a reciprocating engine of equivalent power.

As a result, an order for a complete gas turbine cogeneration facility was issued at the end of October 1994. The main equipment was shipped at the end of September 1995, the commissioning and the performance tests were completed by mid-December and the plant takeover by the client took place on December 28, 1995.

The Cogeneration Plant

The 525 °C gas turbine exhaust gases are sent to a heat recovery steam generator (fig. 9). The 7 tons/hour of steam produced are integrated with the output of the existing boiler that can be modulated to cover the peaks. Integration of the traditional boiler in the process is important to achieve smooth operation of the paper production cycle when the cogen plant is shut down (e. g. for maintenance) and then put back into service.

At the HRSG exit, the 160 °C flue gases are sent to the paper machine hood to dry the product. An extraction fan is used to maintain a slight depression inside the hood to avoid leakage of the combustion products. The extracted gases, at around 120 °C with a high content of water vapour, are then sent to a heat exchanger to preheat air that is drawn into the hood by the depression created by the fan. Finally, a part of the exhausted flue gas at 70 °C is sent to a scrubber to preheat water. This highly optimized heat recovery scheme makes it possible to achieve an overall fuel efficiency over 96% in ISO conditions. Two diverters and by-pass stacks are used to keep the gas turbine in operation excluding the HRSG and/or the paper drying.

Part of the treated water is used for injection into the gas turbine combustor to achieve the contractual emission of 100 mg/Nm³ NOx emission referred to 15% oxygen (dry).

In the design of the plant electric grid (figure 10) consideration was given to the possibility of increased electricity requirements in the future. For this reason, the granted supplies have been kept separate from others of lesser importance. It is therefore possible to cut off non critical supplies in case of failure of the external grid supply when the power provided by the gas turbine generator is below the total plant requirement.

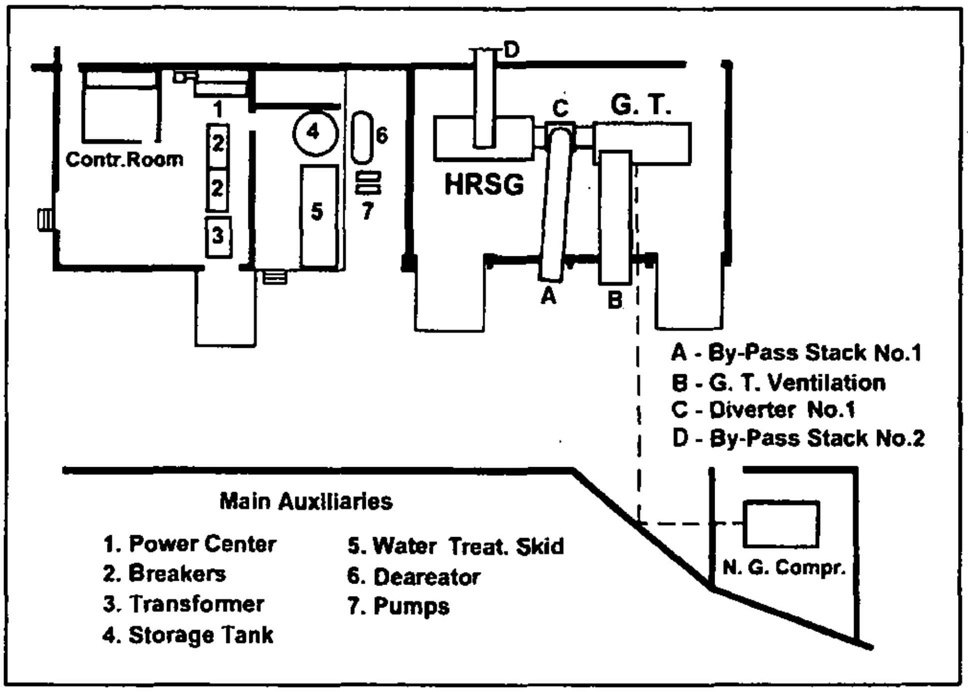

Fig. 11 Paper Mill Cogeneration Facility Layout

The arrangement of the main equipment and auxiliaries is shown in figure 11. All the material belongs to the contractual cogeneration plant turn-key scope of supply. The installed gas turbine module can be seen in figure 12, while figure 13 shows the no.1 diverter and the vertical once-through steam generator arrangement.

A 4-year full service assistance and maintenance contract has been signed, with the possibility of having skilled people available on site within hours at a call. The contract includes real time monitoring of the gas turbine and cogeneration plant parameters. This is achieved through a dedicated telephone line and modem connected to a personal computer in Nuovo Pignone's main plant in Florence.

Operating experience

During the first months of operation, the heavy dust content in the plant atmosphere caused a rapid fouling of the inlet filter. The problem was solved with a more efficient filtration system fitted directly inside the existing filter chamber. After the filter replacement, the gas turbine performance returned the new machine levels, thus showing a very good resistance to fouling of the high speed centrifugal compressor. The gas turbine-generator set showed excellent behavior when suddenly switching to isolated grid operation due to relatively frequent disconnections of the external grid not related to the cogeneration plant operation. In all cases, as soon as the external cause of interruption ceased, the synchronizing with the grid was performed automatically and smoothly by the control system without interfering with the paper process at all.

In terms of performance, a 3 to 4% higher output electric power capability has resulted with a heat rate in line with the contract. Also steam production exceeds the design figure by about 5 to 6%. Such a superior output capability, particularly for steam, further improves the fuel utilization factor and consequently also the expectations for economic return.

ADDITIONAL APPLICATIONS OF THE PGT2 GAS TURBINE

Besides the unit just described, another five PGT2 turbine-generator sets are presently undergoing installation or construction. Of these, one is for cogeneration in a textile industry, while the other four are for paper mills. In one of these units, only part of the exhaust gases are sent to a steam generator, while the rest is sent directly at 525 °C to the paper drying section ("Yankee Hood"). It is interesting to note that this direct use of high temperature gases will be the first application in Italy and one of the first in the rest of the world.

Of the other applications currently under negotiation, it is worth noting that a number are for tile factories. In this case, the entire exhaust flow is further heated to 550 °C with afterburning and then sent to a product spray dryer. At the exit the flue gas temperature is around 100 °C and can be sent directly to the stack. This application is very attractive economically, due to the low capital cost on account of the complete absence of the steam plant and of need for further downstream heat recovery due to the low dryer flue gas exit temperature.

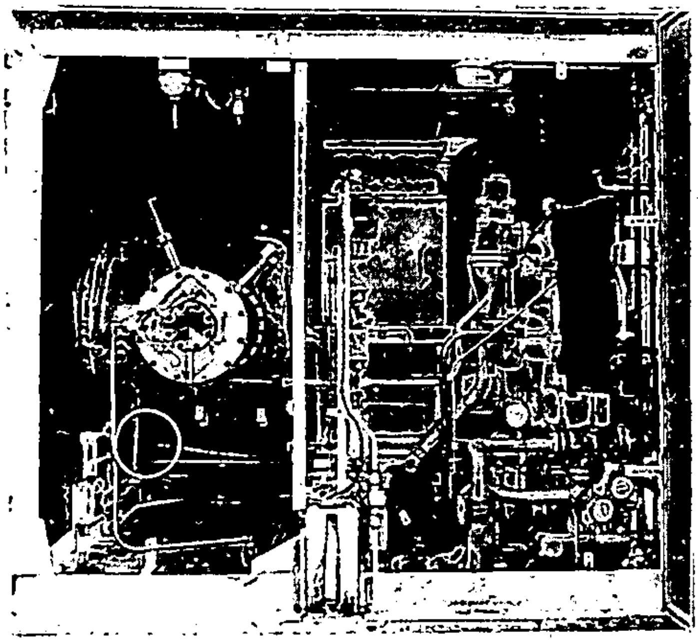

Figure 12 G. T. Module - Combustor and Accessory Side

Figure 13 G. T. Package, Diverter and Vertical HRSG

CONCLUSIONS

The good market response to introduction of the 2-MW class PGT2 gas turbine to industrial cogeneration service is confirming that the main design goals set at the beginning of this project have been substantially correct. The match of advanced but well proven gas turbine technology with heavy-duty industrial machine concepts has resulted in a compact and rugged assembly, simple to operate and to maintain. These features, associated with a simple and rational accessory layout, are being appreciated by customers in the small power cogeneration market that have in general little familiarity, if any at all, with gas turbine engine technology.

Another feature that is achieving a very positive client response is the availability of a custom designed once-through exhaust heat recovery steam generator, that can be fitted directly into the vertical exhaust stack. The substantial space saving made possible by this configuration with respect to the use of a conventional steam generator allows the PGT2-based cogeneration units to be fitted in the usually limited spaces available in existing industrial plants.

The cogeneration design work for the orders which have been won or are under negotiation has received great customer appreciation for the support given by the supplier to an accurate integration of the new heat and power system with the industrial process. This assistance becomes increasingly important along with the degree of complexity in the heat recovery schemes necessary to achieve extremely high fuel efficiencies even in small plants.

The operational experience acquired so far, although limited, has confirmed the flexibility and adaptability of the proposed cogeneration scheme to industrial production cycles, as well as the capability of achieving the energy cost saving and capital pay-back time targets.

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