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PG5361 STEAM INJECTED COGENERATION PLANT

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ABSTRACT

This paper gives a short description of the first-in-China steam-injected gas turbine plant for use in power stations. The adoption of steam injection techniques can lead to a significant enhancement in power output and sizable reduction in oil consumption rate.

INTRODUCTION

Since the first in the world commercial dual-fluid parallel-compound cycle (i.e. steam injected gas turbine or STIG cycle) plant was officially put into commercial operation in 1985, the ensuing few years have witnessed a dramatic development of such STIG plants. The characteristic features of a STIG plant can be summarized as follows:

- high specific power
- high efficiency
- high flexibility in achieving a balance of thermal and electrical loads
- reduction of NOx content in exhaust gas emissions.

Mainly employed in cogeneration plants and electric power generating units, STIG plants pertain to one of the key research projects under intensive study worldwide during the eighties by engineers and scientists active in the field of energy and power generation.

At Shenzhen Nanshan Thermal Power Generation Co., Ltd. Shenzhen, China, are installed three PG5361P1 gas turbine power generating sets. As it is very hot in Shenzhen and the said units are already advanced in years, they have been operating year round at a capacity far below their nameplate power rating. In addition, due to the presence of heat energy users near the power station, a modification of these units to STIG plants for a cogeneration role will bring about significant benefits through an improvement in plant operating efficiency. As the Harbin Marine Boiler & Turbine Research Institute had done a great deal of research work on STIG plants during the years 1984-1989 and set up a STIG test rig on which numerous tests had been conducted, the above proposal concerning a STIG-oriented modification was accepted with the Institute assuming the role of a general contractor for the turnkey modification project.

STIG PLANT

On Fig.1 is shown a schematic diagram of the PG5361 STIG plant.

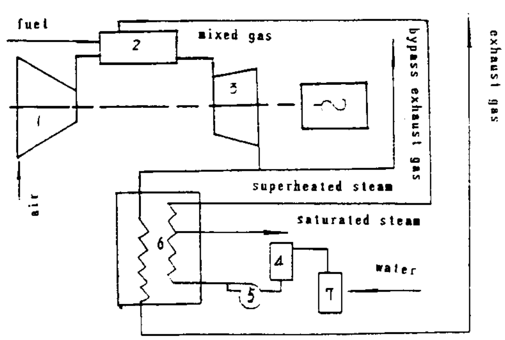

Fig.1 Schematic drawing of PG5361 STIG plant

1 compressor
2 combustor
3 turbine
4 deaerator water tank
5 pump
6 heat-recovery steam generator (HRSG)
7 water treatment unit

Air after passing through a compressor flows into a combustor, where fuel is injected. A second working medium (water) is turned into steam after absorbing waste heat of the turbine exhaust (a mixture of gas and vapor) in the HRSG. A certain amount of saturated steam is led out from the HRSG to heat energy end-users. Another portion of the saturated steam is transformed into superheated steam after flowing through a superheater and is injected into the combustor by way of a special injection system. This steam mixes with the high-temperature gas

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resulting from combustion and enters a turbine to do expansion work. Then, by way of the HRSG it is finally exhausted into the atmosphere. Of course, by a switch-over of a three-way flue damper the gas turbine can still operate as a simple cycle unit. Fig.2 is an external view of the whole plant.

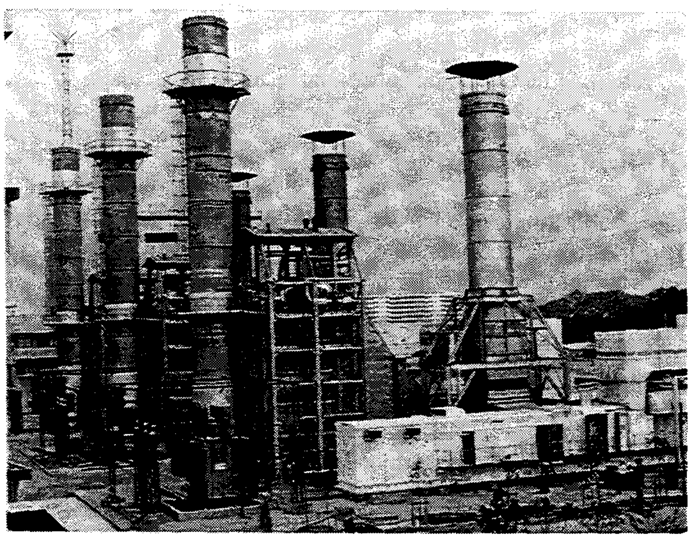

Fig.2 A photo of the external view of PG5361 STIG plant

The heat supply system main piping for the three sets of plants are interconnected while their steam injection systems are independent of one another. As stipulated by the power station authorities, the plant system shall mainly meet heat supply requirements with the excess steam going for steam injection in order to increase electric power output and reduce oil consumption. Thus, with the steam injection serving as a means of heat load regulation the STIG cycle fully features a flexible matching of the heat and power loads.

Gas Turbine Power Generating Sets

The basic engine is an outdoor packaged PG5361P1 gas turbine manufactured by Alsthom Co. of France. Its characteristics under ISO conditions are as follows:

power output: 24,690 kw (when operating on light oil)
air intake: 436,000 kg/h
oil consumption: 7,600 kg/h (when operating on light oil)
flue gas exhaust rate: 439,000 kg/h
exhaust gas temperature: 493°C
heat rate: 13,190 kj/kw.h
speed: 5,100 rpm.

The electrical generator is of T174-160 type with an open ventilation cooling system. Its characteristics are as follows:

power output: 30,862 KVA
speed: 3000 rpm (50 Hz)
power factor: 0.8
outgoing line voltage: 11,000 v.

Heat Recovery Steam Generator (HRSG)

The HRSG is a dual-pressure natural circulation boiler without supplementary firing with the high pressure steam being intended for injection and supplying heat and the low-pressure steam serving as heating steam in a deaerator. Fig.3 is a HRSG schematic drawing. The exhaust gas from the gas turbine flows through a superheater, high pressure evaporating tube bank, economizer, low pressure boiler evaporating tube bank and finally exhausts to the atmosphere.

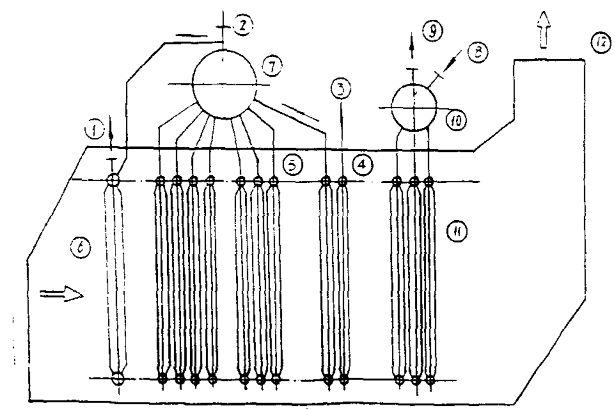

Fig.3 Schematic drawing of the HRSG

1 superheated steam outlet
2 saturated steam outlet
3 high pressure feedwater
4 economizer
5 evaporator
6 superheater
7 high pressure steam drum
8 low pressure feedwater
9 low pressure steam outlet
10 low pressure steam drum
11 low pressure evaporator
12 smoke stack

The design performance of the HRSG can be given as follows:

The steam output shall be 50 t/h of high pressure steam (in which superheated steam totals 30 t/h) and 8 t/h of low pressure steam (0.2 MPa) under the following conditions: the fuel fired, heavy oil; steam injection rate of STIG cycle, 7% (ratio of steam and air quantity); exhaust gas flow rate, 361,083 Nm^3/h; inlet gas temperature, 469°C; feedwater temperature, 104°C; high-pressure steam pressure, 1.86 MPa; superheated steam temperature, 280°C.

For the heating surface is adopted a double-header composite component comprising advanced technology spiral-finned coil tubes with a highly efficient heat transfer rate and an upper and lower header.

The HRSG uses tap water as its water supply source. After undergoing one-stage demineralization and deaeration the water is fed to the boiler.

Fig.4 is a photo of the external view of the HRSG.

Flue Duct

The HRSG for the gas turbine has a fairly large flue duct system and pertinent auxiliary equipment items, including a main smoke stack, three-way flue duct, transition piece, heat expansion compensation element, flue gas damper and a bypass smoke stack. In this set of plant equipment the main smoke stack has a height of 30 meters with the bypass smoke stack being 25 meters high. A single-corrugation metal expansion joint, dual-corrugation metal expansion joint and a non-metal expansion joint are adopted to serve as heat expansion compensation elements in order to ensure a reliable operation of the plant system. The newly developed flue gas damper has rectangular high-temperature motor-driven butterfly valves installed respectively on the main flue duct and by-pass flue duct. The valve body and valve disc with a seal in-between are made of heat-resistant cast iron.

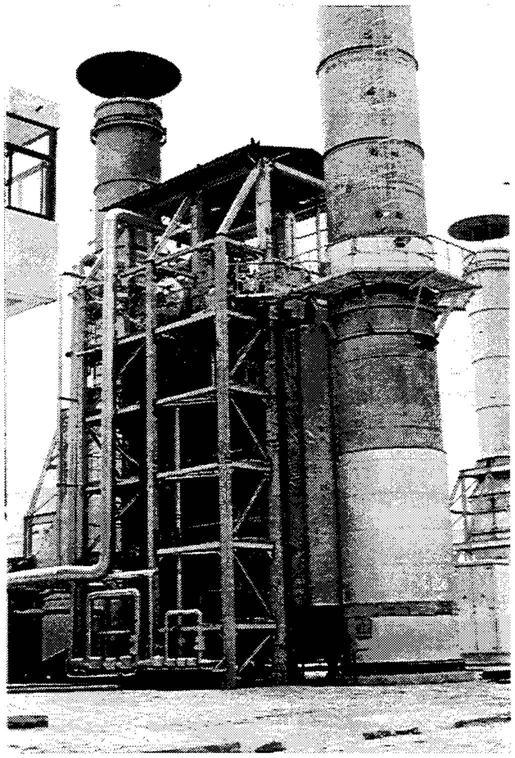

Fig.4 A photo of the external view of the HRSG

Steam Injection System

The superheated steam flows out from the superheater and after passing through a desuperheater and steam filter is led to a steam injection skid. The steam then flows through a pneumatically operated quick-closing valve, vortex flow meter, motor-driven steam regulating valve, check valve, steam distribution pipe and a steam ring tube and by way of a flexible metal hose it is led respectively to small ring tubes of each of the ten combustors. Finally, this steam is injected into the combustor through a steam nozzle. The steam and secondary air mix with the hot gas resulting from combustion and enter the turbine to do expansion work. Please see Fig.5 for its flow diagram.

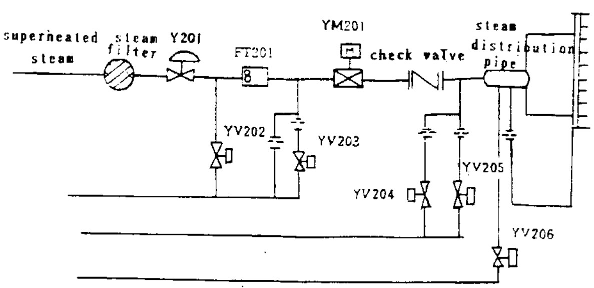

Fig.5 Steam injection system

This system can be divided into two parts:
1. piping and equipment items after the steam filter and ahead of the check valve, which are installed in the steam injection skid;
2. The equipment items after the check valve, such as steam distribution and steam injection device, which are located in the gas turbine enclosure.

A computer automatically controls the steam injection system pipes, preheating, purge piping and the associated valves. The steam injection can be started after all the factors and conditions for steam injection are met.

The parameters of steam being injected are as follows:

steam pressure: 1.67 MPa
Steam temperature: 280 + 30°C
Steam flow rate: 5 t/h ~ 30 t/h.

Compared with a simple cycle (ambient temperature, 22°C; power output, 19 MW), a corresponding STIG cycle with 7% steam injection rate has been found to have the following improvement in performance according to actually measured results: power output increased by 30% and heat rate reduced by 15%.

Fig.6 shows the variation of gas turbine power output increase and heat rate reduction with the steam injection rate.

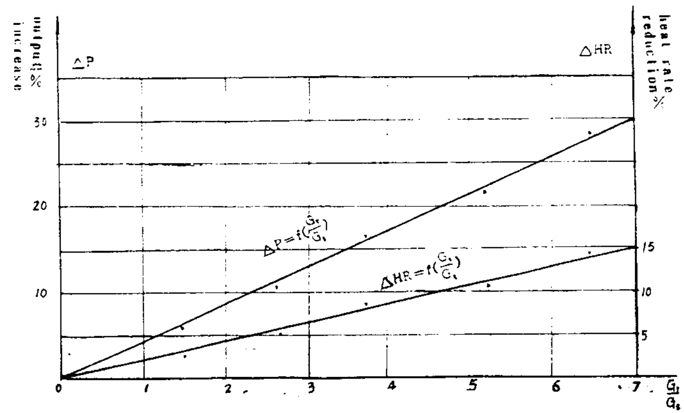

Fig.6 Variation of GT power output increase and heat rate decrease with the steam injection rate

Regulation/Control and Monitoring System

The regulation/control and monitoring system of the whole installation consists of the following three parts:

a. Gas turbine regulation/control and monitoring system

The three existing gas turbine generating sets share one main control room which can monitor some main operating parameters while each gas turbine is controlled and monitored individually in a local control room at each engine end. The gas turbine main control systems include start-up control, speed control, temperature control and acceleration control. By means of a primary element the gas turbine speed, temperature and compressor outlet pressure can be monitored. Protection systems comprise the following: temperature and speed protection systems, vibration and flame monitoring protection systems, etc.

b. HRSG regulation/control and monitoring system

In coordination with local personnel the start-up and shutdown of the HRSG can be carried out in an integrated control room where automatic regulation of parameters and monitoring of normal operation can also be conducted. The three HRSGs are equipped with ten automatic regulation loops for automatic control or remote control. These loops include automatic control systems for main steam pressure (heat supply main piping pressure system shared by the three HRSGs), superheated steam temperature (one for each HRSG), high pressure boiler water level (one for each HRSG) and low pressure boiler water level (one for each HRSG), etc. The HRSG soot blowing is program-controlled. Remote control is provided for boiler feedwater, blowdown and water drainage, etc. In the control room the following boiler parameters can be monitored: steam pressure, steam temperature and flow rate, feedwater pressure, steam drum water level, flue gas-side pressure and temperature, etc.

c. The control and monitoring system for the steam injection system

Through the use of controllers operators in the integrated control room can start and stop the plant system as well as monitor normal operation and regulate the amount of injected steam depending on heat loads. The steam injection system for each gas turbine forms an independent closed ring flow automatic regulating loop. The pressure, temperature and flow rate of the injected steam can be monitored in the control room. The controllers for HRSGs, steam injection system and feedwater deaeration are arranged in one and the same integrated control room. By use of a microcomputer the main thermal engineering parameters for the HRSGs and the steam injection system can be displayed on an analog diagram, tabulated and printed out. In addition, the main operation parameters can be stored in a magnetic disc. Please refer to Fig.7 for the control panel arrangement of the HRSGs and the steam injection system.

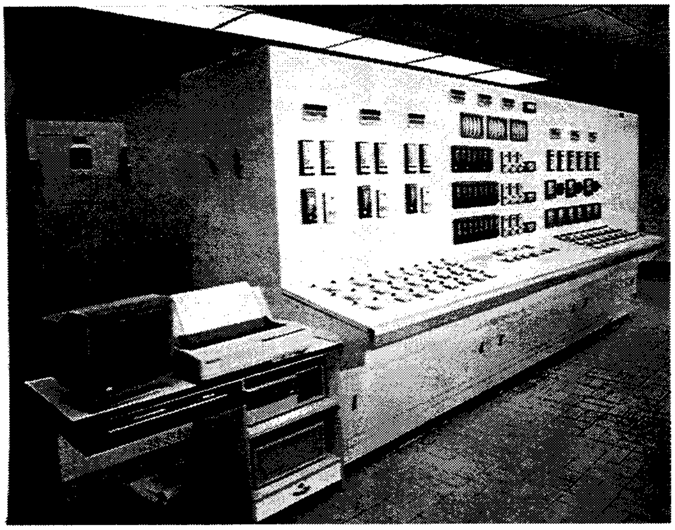

Fig.7 Control panel for the HRSG steam injection system

OPERATION MODE

After modification to the STIG cycle and cogeneration plant the operation mode of a simple cycle gas turbine is characterized by a very high flexibility. The gas turbine can operate either as a simple cycle plant or as a compound cycle one. Under a compound cycle mode the HRSG can operate either fully as a heat supply unit (0% steam injection) or as a unit dedicated fully to steam injection without supplying any heat energy (0% heat supply). When the three HRSGs are all operating, the maximum steam output can reach 150 t/h, the regulation range of heat supply steam output lies between 60 t/h and 145 t/h and that of steam injection lies between 5 t/h - 90 t/h. From the foregoing it can be seen that there exists a great flexibility in respect of matching of heat and electric power load. It should be pointed out that the change-over of operation mode and the matching of heat supply need and steam injection are conducted in the integrated control room by one or two persons with the said matching operation being regulated automatically. Of course, during a start-up a small number of workers should be present on-site to render necessary assistance in smoothing out the operation.

CONCLUSIONS

From the above-cited examples of STIG technology applications it is not difficult to perceive that the modification of existing gas turbine generating sets to STIG plants can bring about great operational and economic benefits. It can eliminate the effect of power output decrease as caused by ambient temperature rise, turbine flow path fouling and extended periods of operation and increase plant power output and decrease heat rate by about 15%, thus directly enhancing economic performance. It can also reduce turbine inlet gas temperature, resulting in a much longer life of the gas turbine unit and indirectly contributing to the realization of significant economic benefits.

Past practice has shown that the STIG plant has the following merits: simple configuration, small space requirement and low capital cost. Generally speaking, the investment can be recovered in only one year or so.

The STIG technique is applicable not only to MS5000 series units but also to any gas turbine units suitable for steam injection.

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