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A NEW SOLUTION TO INCREASE THE PERFORMANCES OF HYBRID GAS AND STEAM TURBINES PLANTS

S.G. VERNICA[1] T. SAJIN[1]

Abstract: *The propose of this paper is to increase the performances of hybrid plants, combining gas turbines plants and steam turbines plants by achieving a high degree of residual heat recovery of exhaust gas of GTP and using it in the STP cycle. From this point of view it has been proposed a new technical solution to increase the performances of hybrid plants.*

Keywords: *gas turbines plants, steam turbines plants, combined cycles, waste gas, steam, residual heat recovery.*

1. Introduction

Gas turbines plants (GTP) run using Brayton cycle, and steam turbines plants (STP) use the Rankine cycle.

Using the comparison of the cycles of these two plants we get two conclusions [2]:

- GTP cycles are more suitable from the point of view of functioning in an efficient way at high degrees of temperature than STP cycles;
- STP cycle is more attractive from the point of view of minimization the temperature interval between the cold portion of the cycle and the cold source.

From these considerations the plants were combinated on the temperatures scale in such manner, that GTP cycle is located above STP cycle, without mixing the two working agents (waste gas and steam).

Another interesting possibility is the direct contact between the working agents. Usually, the steam is injected partially in the air compressor and partially in the combustion chamber of GTP. In this case using steam as an additional work agent of GTP allows increasing essentially the specific power and the plant efficiency and to use more compact heat exchanger equipments than in the case of GTP without steam injection.

The development of the gas turbines in the last four decades, as performances and as operating time, exploitation costs and safety in operation made that these plants become preferred nowadays for the processes with combined cycles [1].

Designing combine gas and steam turbines plant is very complex, because two different power generation cycles are connected to each other via a heat recovery boiler, and any change in its design directly affects variables such as power, efficiency or cost [4]. Therefore, the equipments in use, such as air compressor, the combustion chamber, the gas turbine, the steam boiler, the steam turbine, the electrical generator, must be dimensioned and mounted so that power and efficiency can be obtained in order to satisfy the demands of the consumers with high economic efficiency.

Further is a brief presentation of the

[1] Dept. of “Power Engineering, Mechatronics and Computers Science”, University of Bacău.

known modern technologies of combined gas and steam turbines plants, followed by a description of the proposed hybrid plant with gas and steam turbines.

2. Modern Technologies of Producing Energy with Combined Gas and Steam Turbines Plants

There are known multiple configurations of combined gas and steam turbines plants. These can be with one shaft and multiple shafts. The installation of energy production with combined cycles, with one axle, is composed of a gas turbine, a steam turbine, an electric generator and a recovery boiler. The gas turbine and the steam turbine are coupled with the electric generator on the same line of shafts. The installation with multiple axles of shafts has one or more gas turbines and recovery boilers that provide steam through a common header to a single steam turbine (Fig.1).

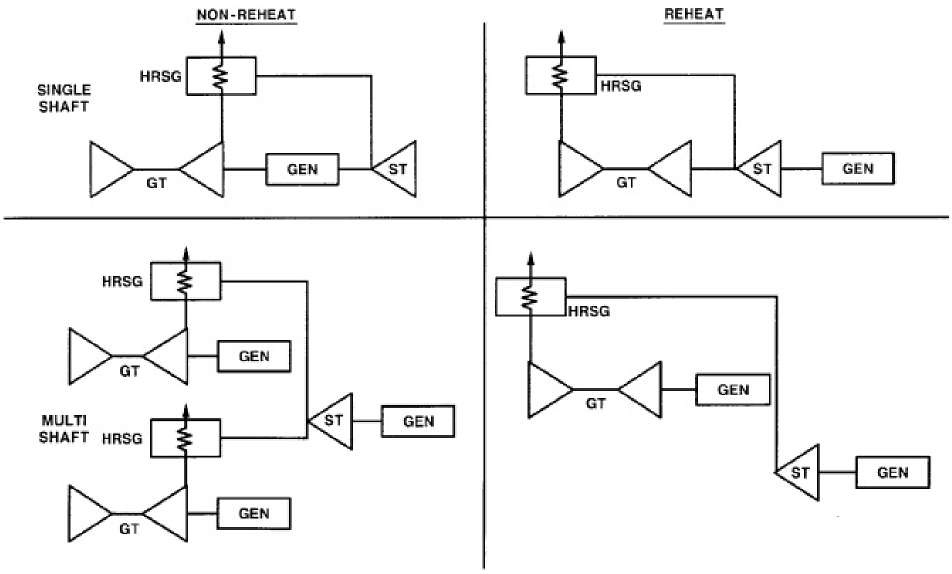

Fig. 1. *Various configurations of combined plants with gas and steam turbines [3]*

There have been studied and built plants of this type for simultaneous production of electrical and thermal energy by companies such as: General Electric, SUA; ABB-Alstom, Switzerland; Westinghouse Siemens, Germany; Mitsubishi, Japan.

Depending on how the primary energy is introduced and on the type of the thermodynamic coupling between gas cycle and steam cycle, the following categories of combined gas-steam cycles can be distinguished: *cycles type "series"*, in which the primary energy is introduced only in gas cycle, the one with steam being strictly recovery and the heat obtained from burning fuel get through both steps of the thermodynamic cascade (for this type of combined cycle the greatest values of the thermal efficiency is obtained); *cycles type "parallel"*, in which the primary energy is introduced simultaneously in the gas cycle, respectively the steam one, and from the thermodynamic point of view it can't be told that there is a coupling between the two cycles, the connection being strictly technological (both gas turbine plant and steam turbine plant work independently); *cycles type "series-parallel"*, in which a share of primary energy will cross the whole thermodynamic cascade, the rest being introduced directly into the steam cycle and the efficiency is lower than in the case of the cycles type "series".

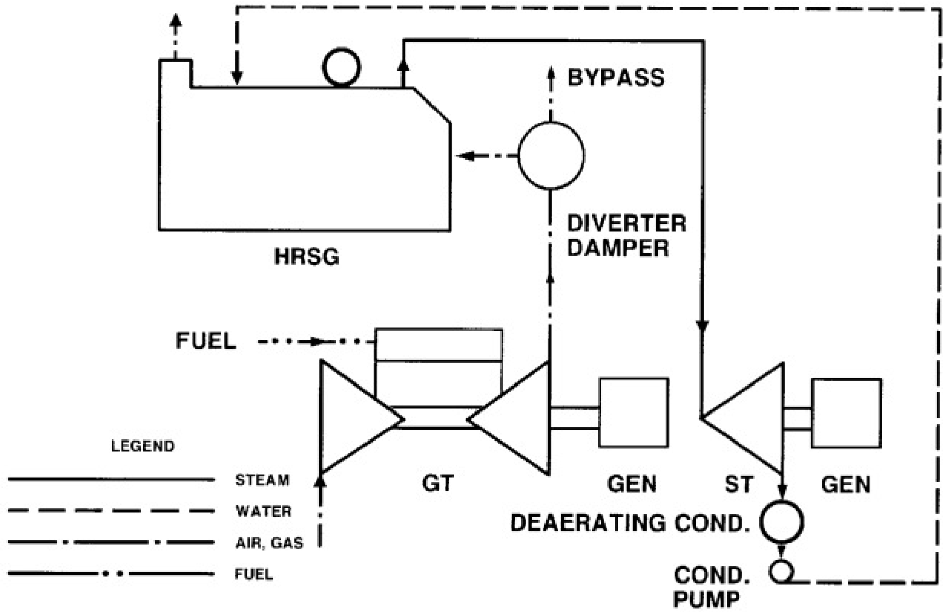

Fig. 2. *Plant with combined cycles type "series" [3]*

In Fig. 2 is presented a scheme of a plant with combined cycles of type "series", where the recovery boiler consists of three sections: superheater, evaporator and economizer. Energy is recovered from the exhaust gas by the gas turbine by convective heat transfer. This is the simplest steam cycle that can be applied in a combined cycle, this one being used for exhaust gas temperature of approximately 538°C or less. The temperature of the burnet exhaust gas from the recovery boiler for this steam cycle is approximately 171°C.

3. Combined Gas and Steam Turbines Plant

The proposed solution is to develop a combined gas and steam turbines plant [5] with a high degree of recovering the heat from the waste gas, which works in a heat power regime with cogeneration of electrical power, of the technological steam and of the hot water at a high thermal efficiency.

In Fig. 3 it is represented the main scheme of the combined gas and steam turbines plant; in Fig. 4 there is the cross section through the stack and the air preheater, section A-A from Fig. 3.

The combined gas and steam turbines plant consist of a gas turbine (1), on the rotating axle (2) on which it is mounted an air turbo-compressor (3) and an electrical generator (4). The underpressure combustion chamber (5) is coupled to the flow pipe-line (6) of the air turbo-compressor (3), to the input pipe-line (7) in the gas turbine (1) and to the pipe-line fuel supply *(a)*.

On the gas part *(b)*, a steam boiler (9) with heat exchangers (10), (11) and (12) is connected to the output pipe-line (8) of gas turbine (1); on the route of the waste gas *(b)* the heat exchangers are located in the following sequence: steam superheater (10)- vaporizer (11)- economizer (12). The steam boiler (9) is connected through a closed water-steam circuit with a heat power steam turbine (13) with adjustable steam bleeds (14) to deliver the technological steam *(c)*, with a steam condenser (15), which has input pipe-lines (16) and output pipe-lines (17) of cooling water *(d)* and with a degasser (18) having at input and at output a feed pump (19) and (20). On the rotation axle (21) of the steam turbine (13) it is mounted another electrical generator (22).

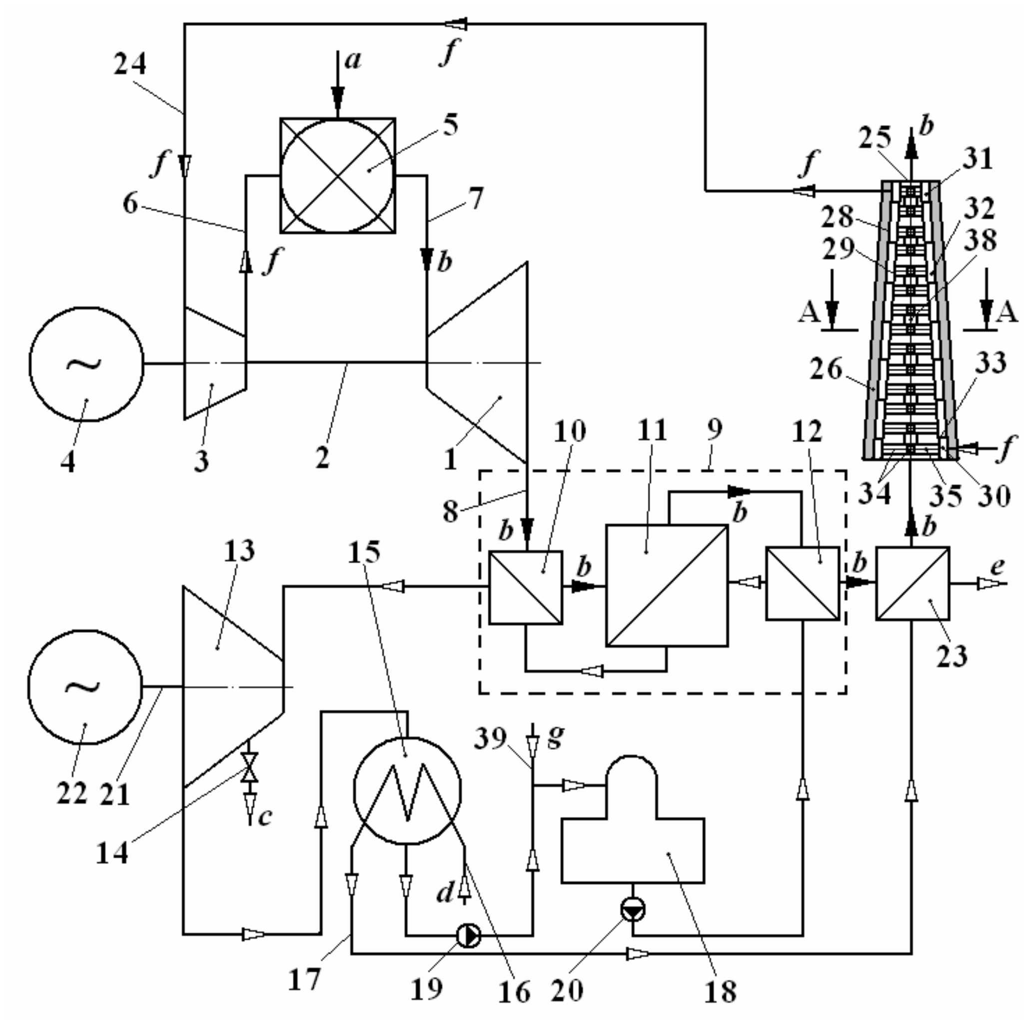

Fig. 3. *The main scheme of the combined gas and steam turbines plant*

The plant has a supplementary heat exchanger (23) in order to prepare the hot water *(e)*, located on the route of waste gas *(b)* after the economizer (12) and on the water part it is coupled to the output pipe-line (17) of the cooling water *(d)* of the steam condenser (15).

The plant also has an exhaust device of the waste gas *(b)* into the atmosphere, which has an air preheater *(f)* coupled to the suction pipe (24) of the air turbo-compressor (3). The exhaust device of the waste gas *(b)* into the atmosphere is made in the shape of a stack (25), which is thermal insulator on the outer side with thermal insulation (26). The air preheater is made in the shape of a peripheral covering (27), formed between the masonry (28) of the stack (25) and a metallic carcass (29), coaxial with the masonry (28) of the stack (25). The peripheral air covering (27) is sectioned on height on marginal sections (30) and (31) and on intermediate sections (32), and they are separated by horizontal diaphragms (33). On the part of the waste gas (b) the peripheral air covering (27) has ribs made of sets (34) of radial pipes (35), which communicate with peripheral ends (36) with those sections (30), (31) or (32) of the peripheral covering (27) and with opposite ends (37) with central collectors (38). This way, to the marginal sections (30) and (31) are coupled a set (34) of radial pipes (35), to the intermediate sections (32) are coupled two sets (34) of radial pipes (35), and the central collectors (38) couple the opposite ends (37) of the sets (34) of the neighboring pipes situated in different sections of each pair of adjoining sections. The radial pipes (35) of each set (34) are positioned in relation with the pipes of the previous set (34) on the height of the stack (25) with an angular change of place in horizontal plane of 45°.

The returned condensation *(g)* from the thermal consumers of technological steam *(c)* gets into the degasser (18) through the pipe (39).

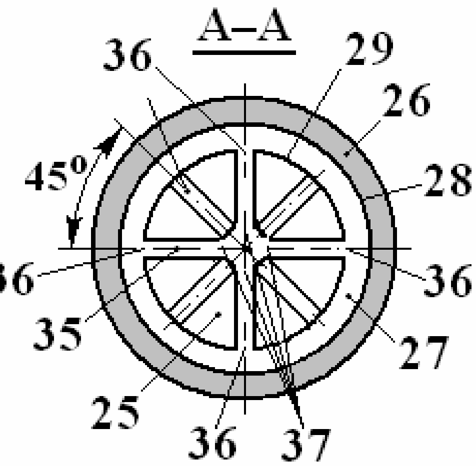

Fig. 4. *Cross section through the stack and the air preheater, section A-A from Fig. 3*

The above combined gas and steam turbines plant works this way: using a start-up engine (it isn’t shown on the scheme in fig.3), the air turbo-compressor (3) starts to work, which suction the air *(f)* from the atmosphere through the marginal section (30) and then continued, successively, through the radial pipes (35) of the sets (34) and central collectors (38), through each intermediate section (32), through marginal section (31) and through suction pipe (24). The turbo-compressor (3) compress suctioned air *(f)*, which it is discharge through the pipe (6) into the underpressure combustion chamber (5). In the chamber (5) the compressed air is mixed with the inlet fuel from the pipe-line *(a)* and it is injected into the jet of compressed air. The combustible composition ignites and burns underpressure in the chamber (5), generating hot burnt gases.

The hot gases *(b)* underpressure are admitted through the inlet pipe (7) in the gas turbine (1), in which they expand, turning the turbine (1) rotor, continuing to drive the air turbo-compressor (3), mounted on the same rotation axle (2) with the turbine (1). From this moment, the start-up engine is uncoupled. The turbine (1) drives in rotational motion the electrical generator (4) too, producing electrical power. After expansion, the waste gas *(b)* with higher temperature than the working temperatures of the steam superheater (10), the vaporizer (11), and the economizer (12) and the supplementary heat exchanger (23) are admitted through the inlet pipe (8) successively through these heat exchangers of the steam boiler (9). The order placement of the heat exchangers (10), (11), (12) and (23) in the channel of waste gas *(b)* of the steam boiler (9) correspond to the temperature graph on the cold part of the gas cycle and this way the thermal contact between the cold part of the gas cycle and the warm part of the steam cycle are optimally correlated, ensuring a high degree of heat recovery of the waste gas *(b)*.

The boiler (9) on the account of the recovered heat from the waste gas *(b)* produces saturates steam at the pressure of the warm part of the steam cycle and the superheater (10) superheats it also on the account of the recovered heat from the waste gas *(b)*. The superheated steam slacks in the heat power turbine (13), which drives the electrical generator (22), producing electrical power.

The spent steam is condensed in the condenser (15), yielding the latent heat of condensation to the cooling water *(d)*, which, recovering it, it heats. The condensation is collected by the feed pump (19) and introduced in the degasser (18) where it is degasified. From the degasser (18) the degasified condensation is collected by the feed pump (20) and introduced in the economizer (12) where it is preheated until it reaches the boiling temperature on the part of the recovered heat by the economizer (12) from the waste gas *(b)*. From the economizer (12), the water, which is preheated until it reaches the temperature of saturation, is admitted in the vaporizer (11) of the boiler (9) where boils, transforming it in steam on the account of the recovered heat by the vaporizer (11) from the waste gas *(b)*. Steam cycle repeats.

The steam cycle of the combined power plant produces electrical power in heat power regime. This way the heat consumer is powered by technological steam *(b)* at the pressure and the temperature asked by this from the adjustable bleeds (14) of the heat power turbine (13). The returned condensation *(g)* from the heat consumers of technological steam *(c)* enters in the degasser (18) through the pipe-line (39). To prepare the hot water *(e)*, the cooling water *(d)*, preheated in the steam condenser (15), is carried through the pipe-line (17) and it is heated until it reaches the temperature asked by the heat consumer on the account of the recovered heat from the supplementary heat exchanger (23). The greater is the heat flow delivered to the heat consumers, the less is the quantity of the electrical power produced by the turbine (13) in heat power regime and vice versa.

The final recovery of the residual heat of the waste gas *(b)*, before the evacuation into the atmosphere through the stack (25), takes place in the air preheater of the stack (25). Because of the proposed construction of the air preheater, the cold air *(f)*, absorbed through the marginal section (30) penetrates from this through the peripheral ends (36) of the pipes (35) of the assembly (34), with which it is connected this section, through the pipes (35) and the central collector (38) and from this one into the pipes (35) of the assembly (34) situated above in the neighbor intermediate section (32). Next, this cycle repeats from section to section as the air is rising to the marginal section (31). This rising is composed by radial periodical movements of the air *(f)* through the vertical pipes (35), with the return to 90º through sections (30), (32) and (31) and the central collectors (38), fact that increase the distance of the air flowing, the area and the intensity of the heat exchange between the waste gas *(b)* and the air *(f)*. The location of the radial pipes (35) of each assembly (34) in relation to the pipes of the previous assembly (34) on the height of the stack (25) with an angular change of place in horizontal plane of 45° (plan position) avoids the formation of stagnation zones of the gases flow *(b)*, which along with the rib shape of the metallic carcass (29) lead to the intensification of the heat exchange and the growing of the exchange area on the part of waste gas *(b)* too. This way, the heat exchange between the waste gas *(b)* and the air *(f)* takes place through the wall of the metallic carcass (29) and through the walls of radial pipes (35) and of the central collectors (38). The preheated air *(f)* is absorbed by the turbo-compressor (3) through the pipe-line (24).

The combined gas and steam turbines plant, under the proposed technology, have the advantages of increasing the heat recovery degree of the waste gas, of working in heat power regime with the cogeneration of electrical power, technological steam and hot water at a thermal efficiency in heat power regime of 80-90%.

4. Conclusions

From the combined cycles of the gas and steam turbines plants type "series", type "parallel" and type "series-parallel", the most indicated are the cycles type "series", in which the primary energy is introduced only in the gas cycle, the steam one being strictly for recovery only and the heat obtained from the burning fuel crosses both steps of the thermodynamics cascade. This type of combine cycle obtains the highest values of thermal efficiency.

Combining cycles can be made without or with direct contact of the working agents. In the first case there are avoided the steam losses and the pollution of the condensation, in the second case the plant is more compact.

In order to increase in performances and thermal efficiency, it was proposed a new combined gas and steam turbines plant.

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References

1. Barbu, E., Petcu, R., Silivestru V., Vilag V.: *Centrale termoelectrice cogenerative cu turbine cu gaze.* Bucureşti. Tehnologiile energiei nr. 4/2007, ISSN 1842-7189.
2. Bejan, A.: *Termodinamică tehnică avansată* (traducere din limba engleză). Bucureşti. Editura Tehnică, 1996, 848 p.
3. Chase, D.L., Kehoe P.T.: *GE Combined-Cycle Product Line and Performance.* GE Power Systems, GER 3574G.
4. Mohagheghi, M., Shayegan, J.: *Themodynamic optimization of design variables and heat exchangers layout in HRSGs for CCGT, using genetic algorithm.* Applied Thermal Engineering 29, 2009, p. 290.
5. Vernica, S.G., Sajin, T., Nedelcu, I., Bîrsan, C., Ostahie, N., Aniței, F., Marian, M.: *Instalație combinată de turbine cu gaze şi cu abur.* Cerere de brevet de invenție nr. A/00163, data depozit 19.02.2009, Cl. Int.[7] F01K 23/10.