

A NEW GENERATION OF LOW COST HIGH PERFORMANCE GEOTHERMAL POWER PLANTS

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ABSTRACT

The financial and economic crisis that is involving the Far East fast developing Countries has caused a sudden setback to the development of geothermal power generation business in that region. At the present, it is extremely difficult to make forecasts on when the recovery process will start. But it is absolutely certain that development process sooner or later will start again. The trend in geothermal power generation, before the stop, was in favor of plants of big unit rating, in the attempt of reducing the capital cost and in turn the cost of electricity. It is expected that this trend will continue with even more strength. This paper will give an overview on the effects on the plant's main equipment (steam turbine/generator, condenser, plant lay-out) in terms of technology, performances and costs. The features of the new steam turbines (blade size, thermo-fluidodynamic design etc.) will be discussed

1.0 INTRODUCTION

The geothermal power generation business suffered in the last year a severe set-back, mainly due to the economical and financial crisis that hit the Far East Countries and specifically a traditional geothermal Country such as Indonesia. As a result, almost all the geothermal projects have been delayed or canceled and the forecasts are that the present situation will continue for some years to come. On the other hand, it is sure that sooner or later the geothermal power generation technology will take-off again, because of its inherent characteristics. One of the most important factors that will push in the future the development of geothermal energy, is the growing importance and consideration being given by the Government to the release to the environment of the so called "greenhouse gases", as a result of the debate developing on a worldwide basis concerning the climate changes due to the greenhouse effect.

As a consequence of the recent conferences held in Kyoto and in Buenos Aires, despite strong resistance put in place by the Government of some Countries, there will be an international agreement aiming to limit and control the release of CO₂ and other gases to the atmosphere. The tools that will be used to achieve this goal are several. For sure among them there will be incentives and mechanism to favor all those power generation processes non depending on combustion of fossil fuels. This will offer new business opportunities to geothermal technology, including the access to the Emission Trading Market that will be generated by International agreements.

Therefore all the operators of the geothermal business must take advantage of the present situation of stall to prepare themselves to meet the challenge of the new market, whose requirements can be easily anticipated:

- low field development costs
- low plant capital costs
- high generating efficiency
- short delivery terms
- low O&M costs
- for developing Countries, lowest possible dependency from imported technologies

ANSALDO ENERGIA, as leading **manufacturer** of power generating equipment, is **working** hard on **some** of the above targets, for the products of its interest. The reduction of capital **cost** is a challenge that **can** be met only **through** a radical redesign **both** of the main equipment and of the plant **configuration**. With the today available **technologies** it is possible **to** increase the unit **size** and the internal architecture of the **steam** turbine, taking advantage of the **experience** gained from the **steam** turbine for fossil power generation, increasing the last stage blade **size**, introducing improvements **on** fluid dynamics, getting **as** a result more powerful, efficient and cheaper machines. The simplification of turbine architecture **will** have beneficial effects **on** plant configuration and lay-out, **with** reduction **on** **cost** of civil **works** and plant infrastructures.

This paper will give a quick overview **on** the possible development of geothermal power generation technology in the direction of reducing plant capital **cost** and improving plant performances.

20 THE PLANT CONFIGURATION

The traditional geothermal power plant, designed for the electric Utilities, reflects the modes and the operational philosophy in use in the **fossil** power plant. Therefore the main equipment is housed in buildings, permanent **lifting** devices are there, everything is lighted, **ai** conditioned, paved, furnished to cope to the requirements of the plant crew.

Private plant operators are more flexible **in** accepting non-conventional plant configuration, such **as** **outdoor** arrangement of main equipment, limitation of permanent building **only** to areas where permanent **occupancy** is needed **or** where electronic equipment are to be located, **use** of mobile lifting **devices** to service **the** main **machinery**.

The **use** of the **outdoor** **concept** for a geothermal power plant gives a big push in the **direction** of reducing the **cost** of civil **works**. The little increase **in** **cost** of main equipment, due to the **need** of **making** them suitable **for** outdoor location, normally in **tropical** highly raining **areas**, is largely **compensated** by the elimination of the building **structures**, their foundations, their **services** (lighting, ventilation, furnishing **etc.**).

The **concept** of using mobile lifting equipment is very suitable for a geothermal **power** plant, which is normally of not big unit rating, if compared **with** a fossil **power** plant. Therefore also the **heaviest** pieces that **need** to be lifted during the operation of the plant (theoretically the generator stator, **but** in the reality the **steam** turbine upper casing with the diaphragms and/or the turbine rotor) **can** be moved using normal mobile crane equipment.

Another big **step** in the direction of reducing the **cost** of civil **works** is **given** by the possibility of **using** **steam** turbines **with** either **axial**, lateral **or** upward exhaust). With either one of the above options, it is possible **to** install the **steam** turbine **on** a "low" foundation (the so called "Qat" solution). **This** involves the elimination of the traditional turbine pedestal, which is used for **both** double **or** single flow downward exhaust (Fig. 1). **The** turbine pedestal is usually the heaviest **concrete** structure of the whole plant. The upward exhaust (Fig. 2) can be "flat" in either **single** **or** double flow turbines, **but** it implies the **use** of bigger and **heavy** cross-over piping.

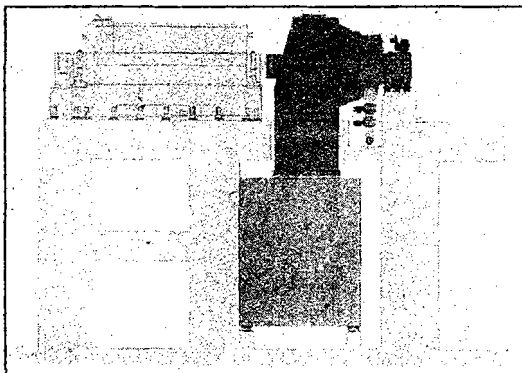


Figure 1. Unit in pedestal installation.

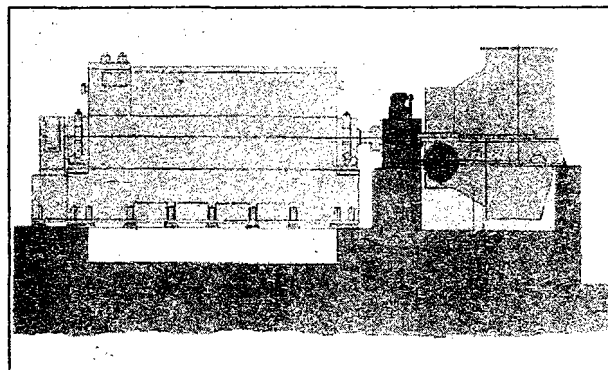


Figure 2. Upward exhaust Unit in low profile installation.

The most attractive option is obviously the so called "axial exhaust" (Fig. 3), because it is the simplest, cheaper and most straightforward solution. This solution involves the use of a single flow architecture machine, otherwise the complication generated from the connection to a single condenser would make vain the effort.

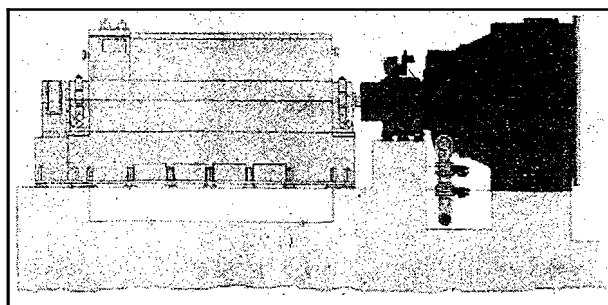


Figure 3. Axial exhaust unit in low profile installation.

A single flow machine will cost 25-30% less if compared to a double flow machine of the same rating. Moreover the single exhaust will give a lot of flexibility in selecting the most suitable plant configuration. The new machine will have the generator drive at the inlet side, making the plant designer free to select the most suitable orientation for the exhaust opening. In this way the geothermal plant, arranged outdoor, with the turbine-generator based at an elevation of no more than two meters above the ground level, with a minimal requirement of excavations and earth movements, will have a capital cost considerably lower than a traditional one. This reduction has a very high value in geothermal plants, which are generally located in volcanic areas, with heavy problems of soil compacting capability, seismic design acceleration and availability of inert for concrete.

3.0 THE STEAM TURBINES

The current practice for the present standard size of geothermal steam turbine, rated in the range 40 to 60 MW, is to make them in the "double flow" configuration, due to the limitation generated by the longest last stage blade traditionally used for geothermal application, which is 650-660 mm in length.

The main concern for limiting the length of the last stage blades was the presence of a high moisture content in geothermal steam which, associated to the high tip speed of long blades, could lead to an erosion damage of the rotating blades.

ANSALDO Energia, starting from the considerations listed above, has developed new last LP stages for its geothermal turbines, using blades directly derived from those used for fossil applications and applying all the counter-measures necessary to avoid the erosion problem due to moisture.

h x pd (inch)	area (sq. ft.)
20 / 60	26.2
26 / 72	40.8

company for geothermal applications.

26 / 91	51.6
33.5 / 99.5	72.7

these blades with number of

Table 2. Last Stage Blades Operating Experiences.

Blade	n° Rows	tot MHR's	max HR's
	38	1.6	
33.5 / 99.5	108	4.8	
NO BLADE FAILURE EXPERIENCED			

The experience refers not only to reheat machines but also to straight condensing ones and even to some nuclear turbines at 3000 RPM with a moisture content in LP steam comparable to that of geothermal units.

The association of long blades **at** full **speed** in the presence of a high moisture content in the steam was well understood and widely applied in **steam** turbines for combined cycle where the no-need of a regenerative cycle encouraged the application of machine “flat” arrangements and axial discharge to the condenser. The **steam** turbine could be practically put **on** the ground as the gas turbine, frequently, in single shaft configuration, thus avoiding the high cost for the pedestal, machine house and associated equipment, erection of the rotating equipment.

In Table 3 is the reported power range attainable in geothermal turbines with three different last stage blades.

Table 3. Power range with long blades.

Turbine	Pa bar	Pc bar	Qa Kg/s	Power Mw	Qa	Power	Steam rate kg/Kwh	Vann m/sec
					SF	SF		
26 x 72"	6,89	0,082	65,7	34,35	131,4	68,7	6,88	259
	10,0	0,082	65,7	37,25	131,4	74,5	6,35	254
	13,0	0,082	65,7	39,3	131,4	78,0	6,01	252
26 x 91"	6,89	0,086	79,7	42,3	159,4	84,6	6,78	238
	10,0	0,086	79,7	45,7	159,4	91,0	6,27	234
	13,0	0,086	79,7	48,1	159,4	95,0	6,02	232
33.5 x 99.5"	6,89	0,082	115,7	60,0	231,4	124,4	6,94	256
	10,0	0,082	115,7	66,9	231,4	134,0	6,25	253
	13,0	0,082	115,7	70,4	231,4	141,0	5,93	250

The study carried out for comparison purpose with three different inlet **steam** pressures, a fixed condenser pressure (typical of wet cooling tower system in a tropical country) and keeping the annulus velocity in its optimum range, shows the possibility to go over 60 Mw with single flow application and over 120 Mw with the double flow (figures do not reflect, for commercial reasons, exact steam rates attainable in specific projects).

Geothermal turbine with single flow LP exhaust in the most common output range of 50-60Mw are then feasible today. They can discharge steam axially to the condenser, thus making the plant not only **more** economical but also more efficient. Reason for better efficiency are:

- reduced turbine leaving losses **as** compared with those of a downward exhaust typical of a pedestal mounted machine
- higher stage efficiency **as** compared with a same rate double flow machine due to better expect ratio of single flow blading.

Moreover there is indication that very high unit ratings, over 120 Mw, **can** be reached in double flow configuration with long blades, thus, avoiding the need of the high cost tandem compound four flow machines built in the past.

In that case a “flat” arrangement **can** still be pursued with **an** upward exhaust and cross-over connections to the condenser.

It is worthwhile to spend some words for what concerns the measures against moisture erosion, considering their importance with long blades. **They** are listed in Table 4 and aimed at:

- reducing water content in the steam before the impact with the last stage blade
- avoid most of the droplet impact with last rotating blades
- protect the blades with special surface hardening or the use **of** “self shielded” material
 - collection slots in last stage nozzles
 - over-shot last stage diaphragm

Table 4. Last stage blades.

Design Features against Moisture
▪ Individual drainage of each turbine stage
▪ Water catchers, grooved buckets
▪ Induction hardening in L-2, L-1 stages
▪ Collection slots in last stage nozzles
▪ Over-shot LS diaphragm
▪ Self-shielding LSB's material

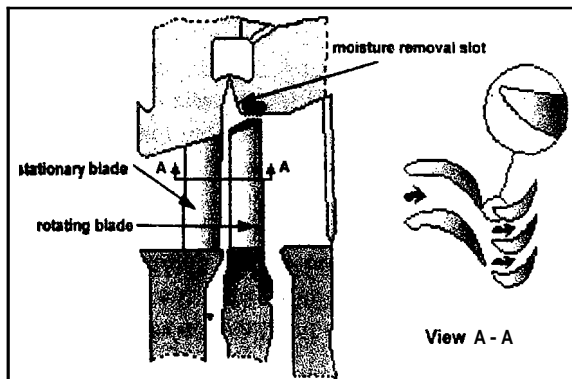


Figure 4. Typical moisture removal downstream of a stationary blading.

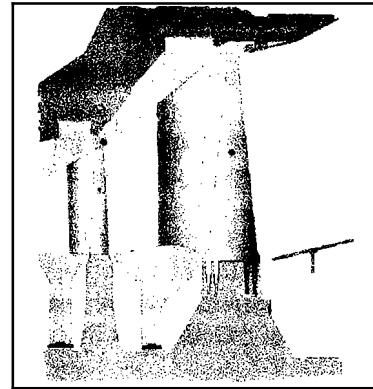


Figure 5. Typical leakage control with overshoot diaphragm.

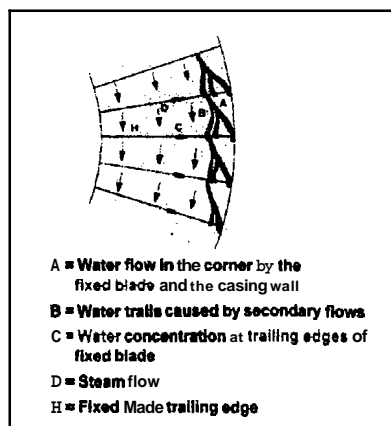


Figure 6. Water flow patterns on fixed blades.

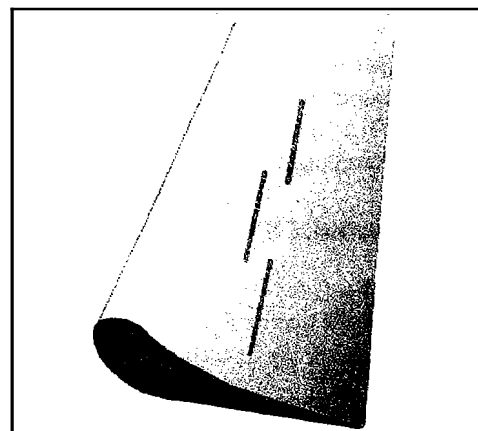


Figure 7. Erosion protection of last-stage rotor blades by incorporating nozzle water removal.

The Same features were already applied to either half-speed nuclear and full speed geothermal machines (Figs. 4 and 5).

The last stage overshoot diaphragm is a feature that drives the water flowing as a film in the corner by the fixed blade or nozzle and the outer side-wall (Fig. 6) over the rotating blade tip avoiding the impact of the droplets with the tip itself as in pervious diaphragms. This measure has revealed as very effective in controlling erosion. Leakage control is assured by a sealing strip placed in the blade cover resulting in a good contribution to turbine efficiency.

Water collection slots in last stage nozzle is a measure taken only in the most critical conditions with stage moisture, outlet pressure, water relative velocity, tip speed that could lead to a high erosion rate. It consist of hollow nozzles cut with slots in the concave side (Fig. 7) to gather the water that tends to concentrate at trailing edge of the nozzle where from the dangerous droplets that impact the moving blades. The slots connect the nozzle outer surface to the condenser through the hollow nozzle and piping (Fig. 8). The pressure drop helps the surface water to the condenser before its concentration in the trailing edge. Direct tests in experimental facility have shown the high effectiveness of this measure.

Besides all the mentioned characteristics, modern geothermal turbines feature new generation of blade profiles designed to give better efficiency through the reduction of profile and secondary losses. Their application can improve the until heat rate by more than 2%.

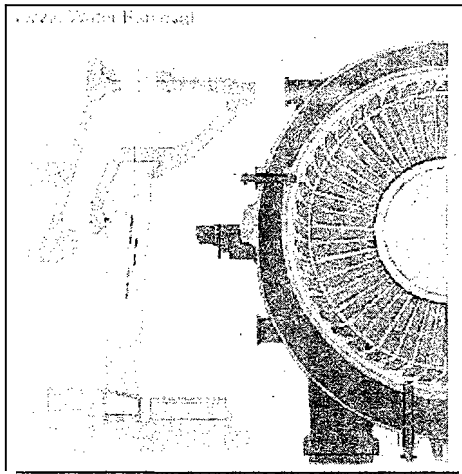


Figure 8. Last stage nozzle water removal.

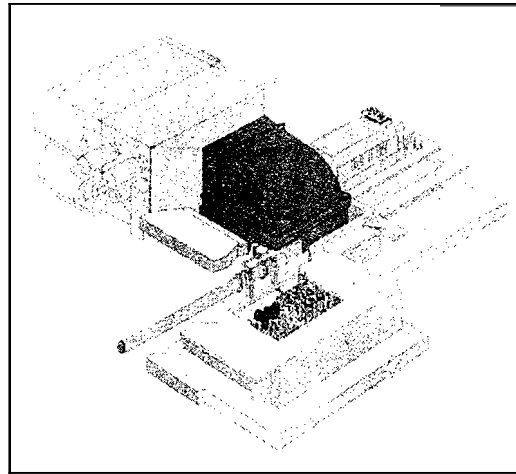


Figure 9

40 CONCLUSION

Radical redesign of **both** main equipment and plant configuration **can** lead to a consistent reduction of capital **cost** in geothermal power plants.

A substantial **contribution** **can** be given **by** the **steam** turbine with the **application** of **last stage** blades longer **than** those traditionally **adopted** so far. Development **efforts**, **experimental** tests, **operational service** together **with** **special** anti-erosion **features**, have **confirmed** their reliability and **suitability** for geothermal **duty**. **Steam** turbines with longer blades **can** be made as single **flow** instead of double **flow**. In **this case** to the intrinsic **cost** reduction **of** the machine is to be **added** that due to the **“flat”** configuration of the unit which means **saving** ion civil **work**, **installation** and **O&M**. Moreover single **flow** machines vs. double **flow ones** give **better** efficiency that **can** be **added to** that due to lower exhaust losses when the discharge to the condenser is axial.

In any **case** with longer blades **even** double **flow machines** **can** become economic in the **high output** ranges **when** it **can** be used instead of a **tandem** compound four **flow** turbine. **An upward discharge** **can** make them suitable for **“flat”** arrangement. Side **discharge** to the condenser is under development (Fig. 9).