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INCREASING THE ENERGY PERFORMANCE OF IRON GATES I HPP THROUGH REFURBISHMENT AND UPGRADING ACTIVITIES

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The refurbishment and upgrading of the Iron Gates I HPP equipment represents, due to the technological complexity and investment effort, the most important and successful project of its category in the Romanian hydro energy system.

Applying the new calculation methods led to a significant modification of the geometry of the rotor blades, with remarkable effects in increasing the efficiency of the hydropower unit and, as a result, in increasing the power of the group as well as the generated energy.

The short term effect of upgrading the auxiliary equipment was simplifying the regular operating and maintenance activity.

Keywords: equipment tear and wear, refurbishment, increase of technical parameters

1. Introduction

SHEN Porțile de Fier I (*Iron Gates I National Hydro-Power System*) was realized by Romania and Yugoslavia in 1970, with a total installed power in the Romanian plant of 6x175 = 1050 MW in 6 units equipped with vertical Kaplan turbines with a 9,5 m rotor diameter that represents also at present a high achievement in the hydro-power field.

The production of energy from *Iron Gates I Hydro-Power Plant* (HPP) represents around 10% of the National Power System (SEN) production of energy and 30% from S.C. Hidroelectrica S.A. production, providing together with *Lotru HPP* almost the entire ancillary services within SEN.

After almost 25-30 years of intense operation the units started to reveal defects showing that a part of the critical subassemblies was rapidly degrading, and it was urgently imposed an ample action of equipment reduction in the

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situation of being able to operate at capacity and in safe mode for another cycle of 25-30 years.

In 1997, RENEL signed a contract with Sulzer Hydro from Switzerland for the refurbishment of the six units. Sulzer Hydro (at present VA TECH Hydro, part of Andritz Group) collaborated at the realization of this work with ABB – Switzerland, as well as with the Romanian companies U.C.M. Reşiţa, Energomontaj, and Electroputere Craiova.

The refurbishment ended in March 2007 and has as main result the increase of energetic parameters of the units and the decrease of the operation and maintenance costs.

2. Need of works

The refurbishment works at Iron Gates I HPP were imposed by the following reasons: long and intensive operation (almost 200,000 hours per aggregate in 30 years of operation); the depletion of the calculated life reserve for more vital components of the hydro-unit and the emergence of the defects related to it; equipment tear and wear; long period for works preparation and realization; the necessity of the governing systems alignment to the UCTE standards; real possibilities of power increase in the conditions of keeping the existing hydraulic circuit.

All these reasons determined the both parties, the Romanian and the Serbian one, involved in the operation of the hydropower and navigation systems from Iron Gates to approach, starting from 1992-1993, the refurbishment of the hydro-units from the two plants under the conditions of increasing the installed capacity. Following the elaboration of some studies, of the execution of some measurement programs and tests in both plants with the initial equipment suppliers, the two beneficiaries, Romanian and Serbian, concluded, within the Romanian-Serbian mixt Commission, governmental working organ, that the refurbishment of the aggregates with the increase of the installed capacity in the two plants is necessary and appropriate. For this, an Agreement between the two Governments and a contract between the two beneficiaries concerning the obligations of each part in this respect was completed and signed.

For contracting the refurbishment works, joint Romanian-Serbian technical specifications were settled that foreseen all the technical conditions in which are to be executed the refurbishment works.

3. Equipment technical status

Iron Gates I refurbishment project had a favorable situation in what concerns the knowledge of the equipment status at the moment of the contract submission, mainly due to the followings:

- the subsidiary maintenance department had a strict and well organized record of the failures appeared during operation;
- a series of technical expertise at critical components was made;
- the existent data made the subject of thorough analysis.

That provided a very good estimation of the necessary works.

We will next shortly present the main hydro-units (HU) deficiencies, which further delineated the implemented technical solutions.

⇨ **Turbine blades** (cast from Cr Ni 13.1 stainless steel) presented:
- *cavitation* in specific areas on the suction side with depths till 20 mm;
- *cracks* in two specific areas (see Figure 1), more precisely blade axis to coupling flange with the hub and the outlet area towards the runner chamber. At unit 6, in 1989, parts of around 460x490 mm^2 broke at blades no 2 respectively no 5, in the outlet area, where the thickness is the smallest.

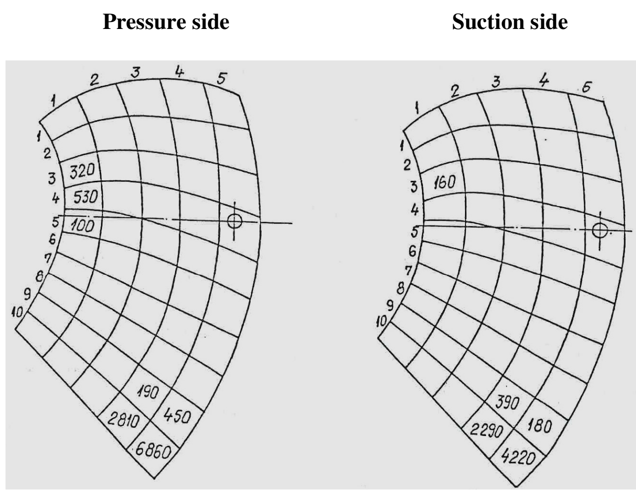

Fig. 1. Cracks distribution on the blade – Total lengths [mm] HU1÷HU6 all the checks from PAC until 1996.

In Figure 2 the timely evolution of the speed development of cracks on old blades (in mm/1000 operation hours) at all 6 units from the commissioning until 1996 is presented.

This graphic clearly presented that the blades were in an accelerated degradation process and were getting closer to the maximum number of solicitation cycles, meaning the expiration of lifetime.

This was confirmed when at the refurbishment of HU2 at one blade a fatigue crack was found in the area of maximum stress.

⇨ **The stator:** At 10 from the 12 stay vanes, cracks appeared in the joint welds with the inferior and superior ring. As a general rule, these cracks (that also appeared in the units from Djerdap I HPP from Yugoslavia), once repaired, would never appear in the same place, but in adjacent areas.

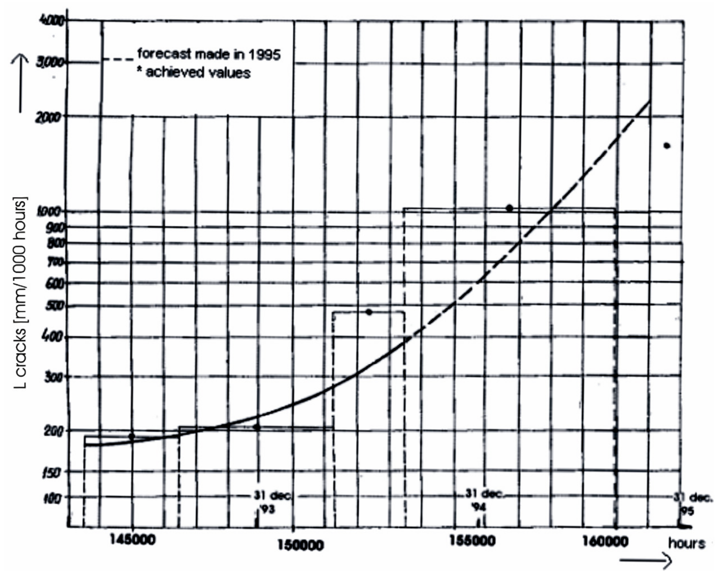

Fig. 2. Timely evolution of cracks speed development.

⇨ **The rotor chamber and manhole:** The main deficiencies were cavitation, cracks and breaking of the metallic embedded parts, gaps between metal and concrete. Must be mentioned the defects frequency, especially cracks, in the manhole area. This manhole was used as access at the blade periphery for the remediation of the cavity on the edge and practically was working as an elastic zone in a rigid element.

⇨ **Runner's hub:** Area affected by cavitation was reported, near the flange of the blades, with orientation corresponding to the most frequently opening angle of the blades.

⇨ **Other subassemblies**: The defects recorded to other subassemblies (oil distribution head, guide bearing, shaft, turbine cover) can be characterized as usual in operation.

⇨ **The generator:** Significant defects of the packet of magnetic steel sheets and of the windings were reported, as well as the inefficiency of the ventilation system.

During the carry on of the works, at the units' dismantling it was observed the fact that the decision of the refurbishment implementation was taken in due time and indeed the initiation of the works could not be delayed anymore. This way it could be seen the fact that the dismantled hubs from the turbines from units 4 and 2 had defects that could in any moment lead to a serious ecologic accident, by polluting the Danube with oil from the interior, and that one of the turbine blades from unit 2 had a crack that could lead to a fault with a long stoppage of the unit.

4. Main applied new technical solutions

For the determination of the constructive solutions, capable to ensure a new 30 years operating cycle, for the main components calculations have been made with the finite element method. These calculations, together with site measurements and tests, lead to the conclusion that the turbine shaft needed to be replaced. At all units the runner blades were replaced with new blades, which geometry, hydraulic profile and energo-cavitational characteristics were model tested in a neutral laboratory.

In order to shorten the process period, a completely new runner was delivered for the first unit. The dismantled hub from the first unit, together with the regulatory mechanism from its interior, was rehabilitated for the next unit, the same procedure being consecutively applied for all the next units. This scheme (which proved to be convenient and which we consider to be generally valid to a refurbishment that has as subject a big number of constructive identical units) was nevertheless disturbed by the fact that 2 hubs (the ones dismantled from units 4 and 2) could not be reused because of their major defects from the past.

The other components were reused after the rehabilitation through constructive modification and modernization.

Main new technical solutions applied at turbine were:

⇨ **Modification of the new shaft geometry**: Through the increase of the nominal capacity of the turbine from 178 MW at 200 MW, the shaft is constrained to increased torsion and axial force. The stress and fatigue calculations led to the following main modifications:

- thickness increase of the shaft cylindrical wall with 45mm, by reducing the internal diameter from 1200mm to 1110mm;
- thickness increase of the two flanges with 60 mm (from 280mm to 340 mm);
- increase of the connecting radius with the flanges.

⇨ **Modification of new runner blades' profile:** The stress and displacement calculations were made for the following entry dates:

material	DIN 17445 G-X5CrNi 13 4, No. 1.4313;
maximum stress	½ from the yield point =550/2=275 MPa;
diameter	9500 mm;
number of blades	6;
net head	31,4 m;
rated speed	71,45 min^{-1};
weight of blade	20.300 kg.

Subsequently, during 2005, the blade's geometry was improved by eliminating the maximum stress area from the connection of the pressure side of the blade with the flange, towards the inlet, by implementing a stress relief groove (see Fig. 3.). In this groove, a demountable, bronze "filling piece" was introduced, not to modify the blade's geometry.

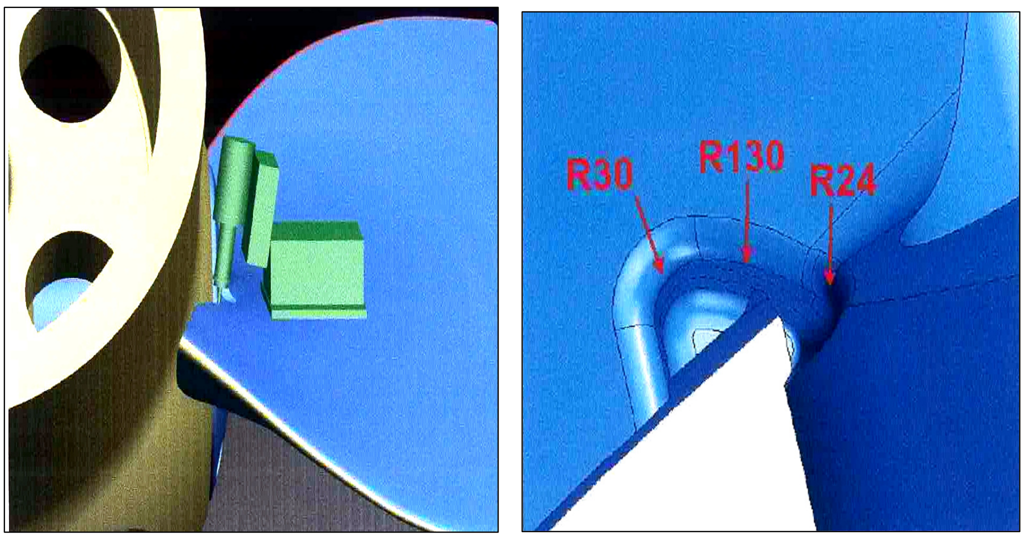

Fig. 3. Stress Relief Groove – execution and geometry.

⇨ **The design of the blade with an anticavitation lip:** Taking into account the numerous repairs that were necessary due to the manhole presence in the runner chamber, through the Technical Specification the designer was requested to analyze the possibility of closing this manhole and to foresee on the outer rim an anti-cavitation lip. The lip's geometry, as well as the material used to protect the area most exposed to the cavitation erosion, made subject of many analysis, tests and corrections, the solution being at present as well subject of optimization analysis.

⇨ **High accuracy in machining and metallic re-coating of runner chamber on the spherical area:** The machining of the runner chamber and the metallic re-coating by sprays with a high accuracy special device, with digital command, installed in the unit's vertical axis, was necessary in order to obtain the medium gap between the blade and chamber, which is relatively small for an unit with a 9,5 m diameter (around 5,5 mm). The cavitation behavior of the spherical area is very good.

⇨ **Modification of the outlet edges profile of the stay vanes** in order to reduce the amplitude of the hydraulic vibrations and the risk of the cracks.

These modifications were done on site, and up to now, (after approximately 7 years from the commissioning of the first unit) no other cracks appeared.

In Figure 4 the new geometry of the outlet edges of the stay vanes is presented.

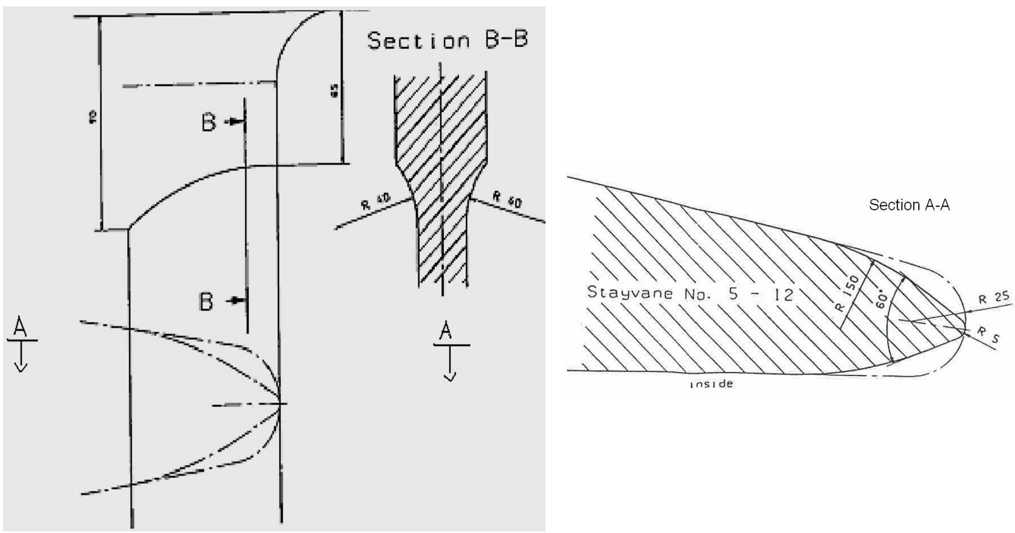

Fig. 4. Stay vane – Modification at outlet edges.

⇨ **Installation of lubricants free bearings** by installation of stainless steel shrinked sleeves and PFTE bushings.

⇨ **Increase of wicket gate blades safety during operation:** Before the refurbishment, each of the 32 blades had one shear pin of OLC45, that were replaced with 16 shear pins of Al-MgSi1 (disposed to every second blade), and 16 pins with higher resistance, of 30 CrNiMo8 steel.

⇨ **Modernization of the lubrication system of the thrust-bearing:** For the lubrication of the thrust bearing a high-pressure oil injection system was installed, supplied by 2 pumps (a working one, and a spear one), having P = 250 bar and Q = 88 l/min, with the necessary modifications to the segments. The 20 oil coolers were replaced with 2 heat exchangers placed in the exterior. The installation operates at the unit's start and stop. This solution proved to be extremely reliable also at other plants in other countries.

⇨ **Other turbine subassemblies:** The main and maintenance turbine shaft sealing were modernized, additional rigidities were made at the turbine cover, the 4 aeration valves from the turbine cover were replaced.

⇨ **Modernization of the governing system:** Each turbine has been provided with 2 independent electronic governor DTL 595 which can be replaced one to another at any moment during operation. The oil pumps (including motors), the instruments for the oil tank and accumulators, as well as the vanes, sensors and measurement instruments of the hydraulic part were replaced.

⇨ **Modernization of the generator:** The magnetic core was modernized, and the air circuit of the ventilation system was reconsidered.

5. Technical performances increased after the refurbishment

The most important technical performances obtained after the **hydraulic turbine refurbishment** are:

⇨ Increase of the average weighted efficiency from 92,9% to 94,1%: It must be mentioned the fact that the Contractor was requested, through the Technical Specifications, to grant an average weighted efficiency. The coefficients were established accordingly to the number of operating hours in different heads and flows ranges. By applying this procedure, the machine designer will practically analyze a bestowed runner, which fits the best in the HPP's operation conditions;

⇨ Increase of the maxim efficiency from 94,24% to 94,74%: This performance, although significant, has economic consequences less important than the ones from the average weighted efficiency;

⇨ Increase of installed flow on the turbine from 725 m^3/s to 840 m^3/s: Taking into account that the construction part was not modified, and consequently after the refurbishment a bigger flow passes through the same section, such modification must be always followed by adequate solutions that counterbalance the cavitation amplification;

⇨ Increase of the rated power at the turbine coupling from 178 MW to 195,1 MW when the net minimum head at which the rated power can be achieved, dropped from 27,16 to 25,5 m;

⇨ Increase of maximum power from 182 MW to 205 MW;

⇨ Decrease of minimum power (minimum technically) from 80 MW to 60 MW.

All these characteristics were confirmed at model tests carried out in the neutral laboratory from Graz Austria in the presence of the Serbian partner and within the performance and index tests (carried out before and after the refurbishment of the first unit) in site, with specialized companies. The tests execution methodology respected the international reference standards IEC 60 193 and IEC 41.

In Iron Gates I, the refurbished 216 MVA **hydro generators** are in all ways superior to the initial 190 MVA generators due to the fact that the implemented solutions have solved all the deficiencies noticed at the initial generators; they have increased performances and up to present no deficiencies occurred.

6. Summary and main consequences of the increase of the technical parameters as a result of the refurbishment works

In addition to those presented above, we could summarize the technical and economical advantages of the refurbishment project of the units in Iron Gates I Hydropower Plant as follows:

⇨ The units are ready for a new operation cycle of minimum 30 years;

⇨ The plant's installed capacity was increased from 1050 MW to 1166.4 MW;

⇨ The energy production for a normal hydrological year increased from 5120 GWh to 5241 GWh. From the commissioning of the first refurbished unit until the completion of the works, the units have additionally generated (due only to the difference between the new and old operation characteristic) more than 1,600 GWh, which is the equivalent of the annual production of two unrefurbished units or of the production on one and a half year of the Lotru hydropower plant. Related to the additional energy that was proved to be generated as result of the units refurbishment, Hidroelectrica has signed a contract regarding carbon credits, which at present is in progress, with Senter Novem – a company which is the representative of The Ministry of Economy in Holland;

⇨ The average efficiency improvement per unit is of 1,5%;

⇨ The regulation band of the group has increased from 95 MW to 134.4 MW, which may lead to significant benefits out of ancillary services: improving the maintenance times and decreasing the number of the unforeseen repairs, thus significantly reducing the costs; increasing the operating safety by setting up monitoring and control systems at aggregate and power plant level.

⇨ Ancillary services in primary and secondary regulation are ensured accordingly to the UCTE requirements.

7. Conclusions

The refurbishment works with the increase of the installed power from the Iron Gates I HPP were necessary and opportune at the moment of the beginning of works in the Romanian plant, thing demonstrated by the necessary time for completing all the necessary stages for approval and preparation of such work, as well as the ascertains during the refurbishment.

The success of the refurbishment works at the units from Iron Gates I HPP was confirmed by the results from the guarantee tests and the operating units' behavior.

The guarantee tests results analysis carried out consequently the refurbishment works with increasing the units' power from Iron Gates I HPP, as well as the analysis of the success of these works were made by the Romanian specialized institutes (ICEMENERG Bucharest and ISPH Bucharest), by University "Politehnica" of Timisoara, Resita Technical University together with

Romanian Academy Timisoara filial and by the Serbian Beneficiary representative. All these analysis showed that the refurbished units' performances were fulfilled accordingly to the contractual provisions and that are at the superior limit of the world performances in the field.

The technical-economical performances carried out and proved, show that the refurbishment project of the biggest hydro-power plant from Romania, Iron Gates I, although a premiere in hydropower field in our country, is an uncontestable success.

REFERENCES

In this article data from the analysis carried out by the Beneficiary's Project team (*I. Bleier – Project Manager, T. Lacatusu, O. Pacuraru, M. Baran, C. Andrei, S. Andrita, I. Daga*) and their consultants, during the entire project period was used.

There was used no data that is intellectual property of the Contractor.