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REHABILITATION OF A GENERATING UNIT AFFECTED BY ALKALI-AGGREGATE REACTION

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ABSTRACT

The Apolônio Sales Generating Station is located on the São Francisco River in northeastern Brazil. It was constructed in the period of 1972 - 1977 and is equipped with 4 generating units of 110 MW driven by Kaplan Turbines. Since the early stage of the commercial exploitation the units presented a abnormal performance with progressive shifting and tilting of the turbine shaft that finally lead to the rubbing of the blades on the discharge ring.

To relieve the stresses caused by the concrete expansion in the embedded parts and restore the assembly conditions of shapes and gaps of the turbine and generator, a rehabilitation program was implemented in the generating unit GR3.

The measurements made before and during the corrections showed unevenness of the turbine head cover, distributor lower ring and generator stator. The discharge ring was oval and out of alignment with the head cover. The stay vanes were distressed.

The accomplished rehabilitation services allowed the return of the power generating unit to the network in a favourable condition to operate together with the AAR for a period of approximately 15 years without needing other similar interventions. The mechanical measurements proceeded in the rehabilitation process provided valuable information for the knowledge of the expansion within the power house structure.

Keywords: Alkali-aggregate reaction, concrete expansion, generator, power plant, rehabilitation, turbine.

INTRODUCTION

The Apolônio Sales Generating Station is located on the São Francisco River in northeastern Brazil. It was constructed in the period of 1972 - 1977 and is equipped with 4 generating units of 110 MW driven by Kaplan Turbines. Since on early stage of the commercial exploitation, the units presented an abnormal performance with progressive shifting and tilting of the turbine shaft that finally lead to the rubbing of the blades on the discharge ring. At the same time cracks in the slabs, beams and walls of the concrete structures were observed. An investigation program concluded that the cause of the problems was the Alkali Silica Reaction due to the combination of granite aggregates and high alkali cement used in the construction. The cement used was Portland type I ASTM, with alkali content superior to 1% (Na_2O equivalent). The concrete mixes had an amount of cement in the range of 350 kg/m^3 (Cavalcanti 1986, 1992).

Besides the periodic inspections and monitoring of the generating units, actions like gridding of the discharge ring, levelling and recentering of the units kept them running. The cutting of 3 expansion slots between the concrete blocks, performed in 1988 - 1992 period, improved the performance of the generating units during some years (Silveira et al. 1989, 1995). Meanwhile, the concrete expansion cumulated stresses and strains in the turbine parts fixed in the concrete, such as the stay vanes, the bottom and the discharge rings. To counteract these effects a rehabilitation process was implemented.

REHABILITATION PROCESS

To relieve the stresses and restore the assembly conditions of shapes and gaps in the turbine and generator, a rehabilitation program was implemented in the generating unit GR3, comprising the following stages:

Demolition of the second stage concrete of the turbine foundation;
Stress relief of the stay vanes;
Levelling of the turbine cover support rings;
Reshaping and repositioning of the lower lip plate and discharge ring;
Repositioning of the turbine runner geometric centre;
Restoring of the second stage concrete of the turbine foundation;
Levelling of the generator braking system bases;
Levelling of the generator stator.
Centering of the generator stator

The remedial measures started with the removal of the second stage concrete at the stay ring bottom side, and continued to the upper part of the draft tube. After the concrete removal, the stay vanes, discharge ring and lower lip plate became free to be displaced. A volume of about 130 m^3 of concrete was removed.

The stress relief of the stay vanes was accomplished by cutting the rib base welds at their lower end. At the upper region of the stay ring the vanes remained fixed to the concrete. After the complete release of the vane, the six base ribs were welded again taking care to minimise the heat-induced stresses. The sequence was such that between the last welded vane and the one being released , there was one vane completely released. The Fig. 1 presents a cross section of the generating unit , showing in the left portion one released vane.

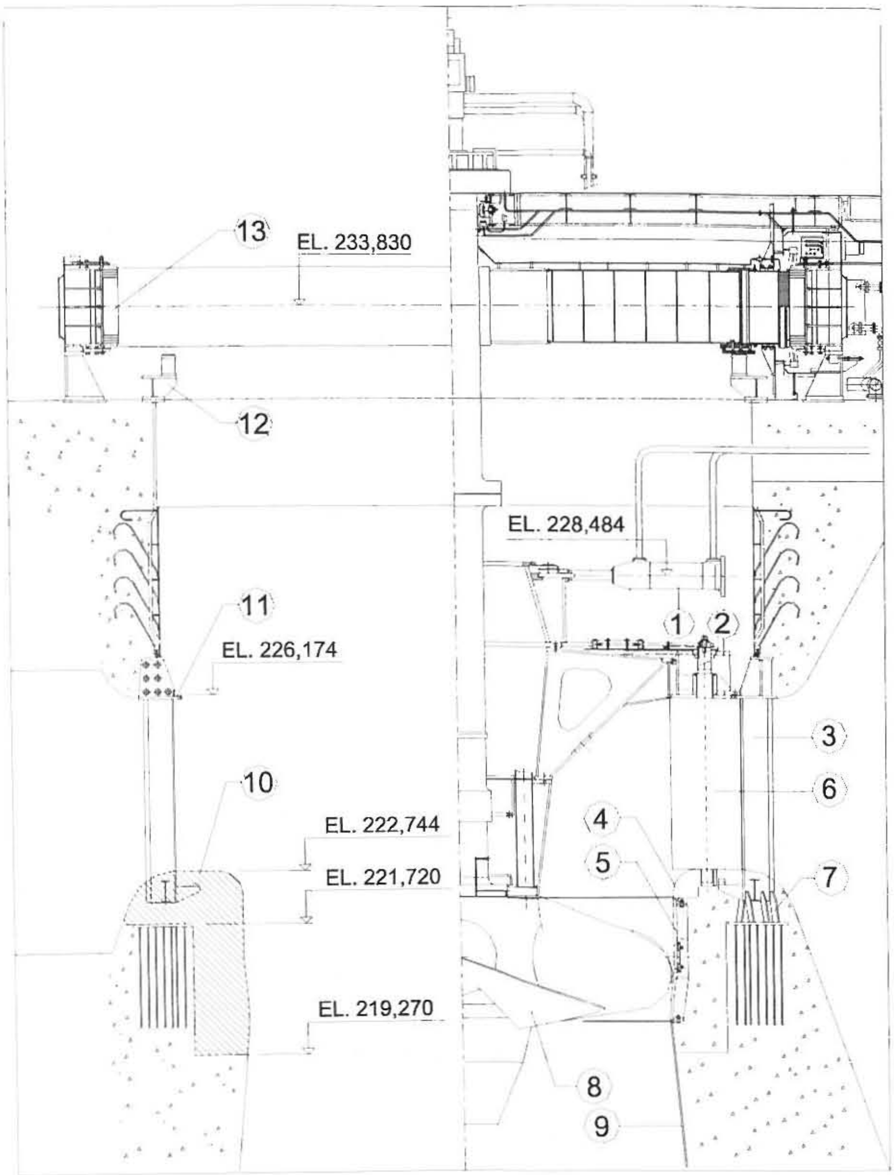

Fig.1: Generating unit cross section

1 Servomotor
2 Outer Head cover
3 Stay vane
4 Lower lip plate
5 Discharge ring
6 Wicket gate
7 Rib

8 Runner blade
9 Draft tube liner
10 Second stage concrete
11 Upper lip plate with Head cover supporting rings
12 Braking system bases
13 Stator

After the stay vanes stress relief, the levelling of the head cover supporting rings at the upper lip plate was performed through the material removal and by grinding and adding shims to get the required level.

To set the new position for the head cover, the relative displacement of the discharge ring to the runner blades, from downstream-right to upstream-left direction, due to the AAR phenomenon, was taken into account. The new position of the head cover was set off centre with the discharge ring, in the opposite direction of that resultant from the AAR, in order to allow a larger gap at the point where the runner approach the discharge ring. This displacement increased the clearance between the discharge ring and runner blades in the downstream-right region by 2 mm. As the theoretical radial clearance is 6 mm, was set the runner blades with a value of 2 mm approximately on the side where the clearance increases and of 10 mm in the side where it decreases. Furthermore, this new position will allow up to 12 mm displacement of the head cover in future, before recentering operations will be required.

The gap closure rate between the discharge ring and runner blades was about 0,85 mm a year. So, one can foresee that the unit will operate for more than 15 years without needing any similar interventions. Fig. 2 presents the situations before and after correction.

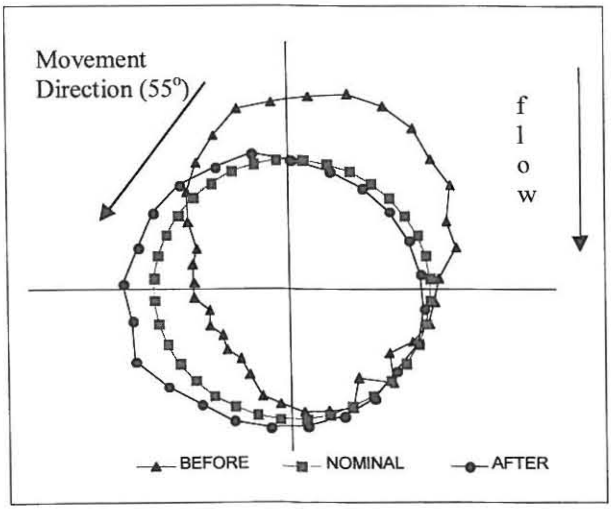

Fig. 2: Relative position between the turbine runner and discharge ring

As the lower lip plate and discharge ring are coupled, the roundness, the flatness and the alignment with the head cover were done through stretchers fixed in the first stage concrete.

Because the concrete expansion causes vertical displacements in proportion to the height over the foundation rock, the generator stator was raised relative to the turbine. A new level reference was set at the downstream servomotor centre level that was found 20,57 mm higher than its original position.

The correction of the generator brake bases level was obtained by cutting its steel bases and the correction of the stator level was accomplished by the vertical displacement of the magnetic nucleus, through the removal of existing shims between the bases and the stator structure.

MONITORING

Before starting the rehabilitation process the following reference measurements were made:

- The vertical alignment between the outer head cover and the lower lip ring;
- The distributor height;
- The roundness of the discharge ring;
- The levelling of the head cover supporting rings and of the lower lip ring;
- The levelling of the generator stator;
- The levelling of the generator braking system bases.

The displacements of the stay vanes caused by the stress relief process was monitored by two three-orthogonal joint meters fixed to the concrete and placed in both sides of the vanes. The relative displacements between the vanes and the foundation concrete were measured in three orthogonal directions with an accuracy of 0.01mm (Cavalcanti et al. 1997).

Head cover Support Rings

The cumulated vertical displacements of the upper lip support rings, since the assembly (Fig. 3) showed an upward range of 17.8 mm near the upstream side to 24.2 mm close to the right bank side, resulting in a 6.4 mm off level.

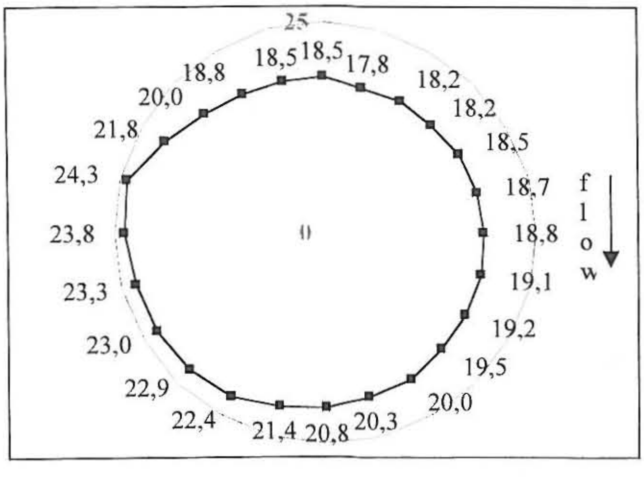

Fig. 3: Vertical displacements of the upper lip ring (mm)

Distributor Bottom Ring

The vertical displacements of the distributor bottom ring was between 16 mm in the upstream- left direction to 19,6 mm in the opposite direction. (Fig .4)

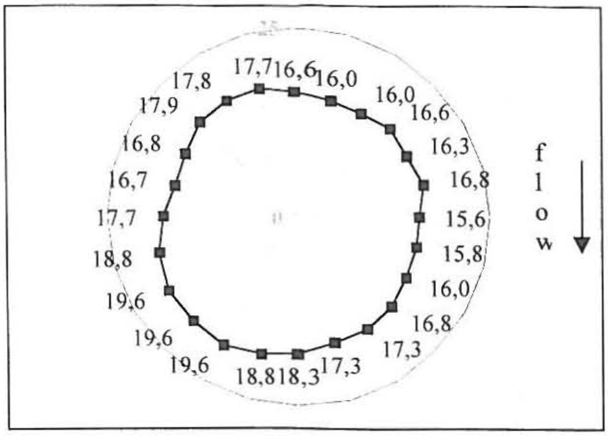

Fig 4: Vertical displacements of the lower lips (mm)

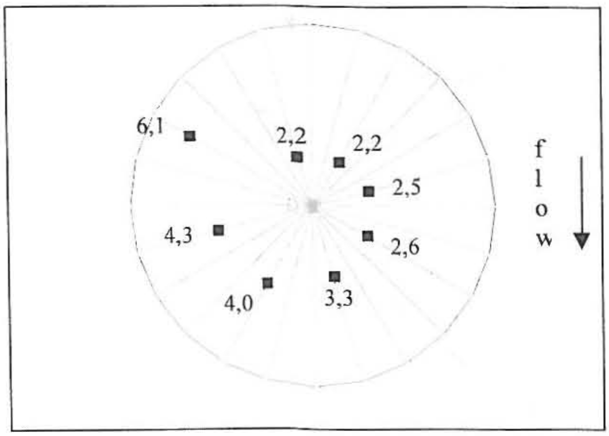

Fig. 5: Distributor height variation (mm)

Distributor Height

The distributor height was controlled by measuring the distance between the distributor lower ring and the head cover bottom side, at eight wicket gates sealing surfaces, to assure the distributor free movement. The distributor height was increased from 2.2 mm near upstream to 6.1 mm at the right-upstream region (Fig. 5). The higher increase at the right semicircle is consistent with the wicket gates vertical clearances evolution (Silveira et al. 1995).

Discharge Ring Roundness and Diametrical Gaps

The roundness of the discharge ring was measured with the intermediate and the outer head cover in place and taking the centre at the shaft sealing centre line. It was measured the roundness of the discharge ring at the Kaplan blades centre level and in planes 0.5 m above and bellow this elevation. The discharge ring roundness at the Kaplan blades centre level presented a maximum ovalling of 14.7 mm and an eccentricity of 9.2 mm, in the direction 35° from upstream, clockwise.

The diametrical gaps between the turbine rotor and the discharge ring , originally 12 mm, varied to a maximum of 19.2 mm and a minimum of 4,5 mm, turning impossible to place the runner with the minimum 3 mm radial gap (Fig. 6).

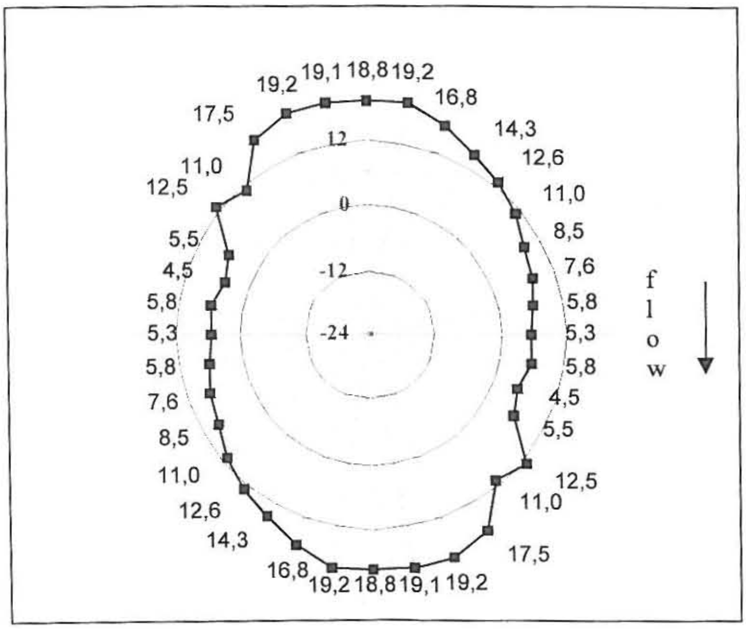

Fig. 6: Runner - discharge ring diametrical gaps (mm)

Stay Vanes Displacements

Horizontal displacements - The horizontal displacements measured by the three-orthogonal meters due to the stress relief, shows movements up to 20.4 mm toward downstream and 17.4 mm toward the right bank side. The displacements scale unit, marked on the axis, is 10 mm (Fig.7)

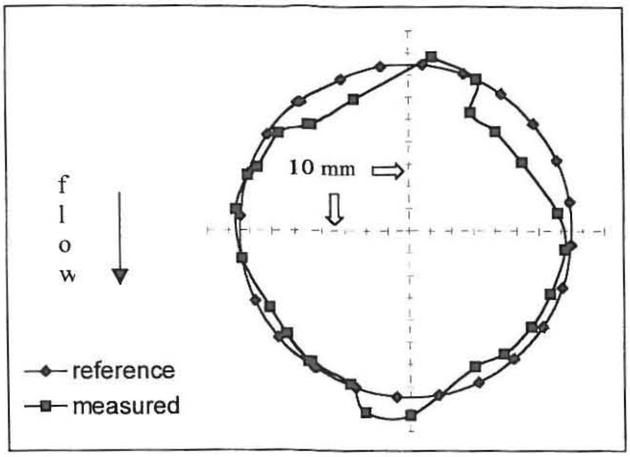

Fig. 7: Horizontal displacements of the stay vanes

Vertical displacements – The larger vertical displacement was near the right bank with 2.3 mm upward. All vanes of the left semicircle had upward displacements indicating tensile stress, while at the right side all vanes, except three, had small downward displacements (Fig. 8).

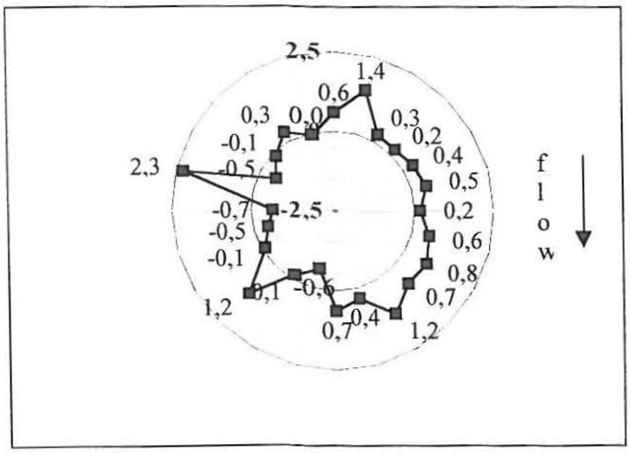

Fig. 8: Vertical displacements of the stay vanes (mm)

Generator Stator Levelling

The generator stator magnetic axis levelling presented upward displacement between 19.4 mm and 25.6 mm related to the nominal level and a maximum difference of 6.2 mm (Fig. 9). As the stator have been repositioned before, these displacements does not reflect the total caused by the AAR.

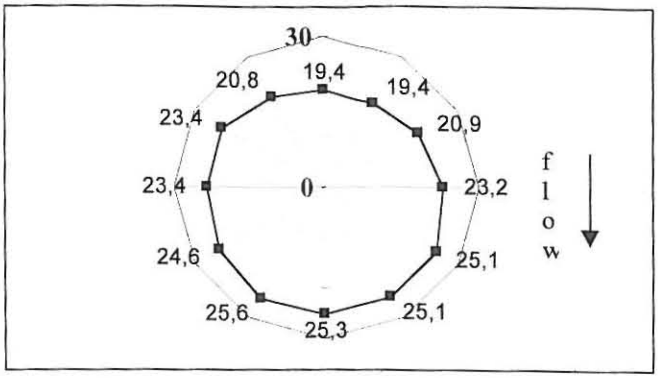

Fig. 9: Vertical displacements of the generator stator.

Generator Brake Bases Levelling

The generator brake bases vertical displacements (Fig.10) varied from 21.8 mm at upstream to 29.4 mm at the downstream-right region, due to the concrete expansion.

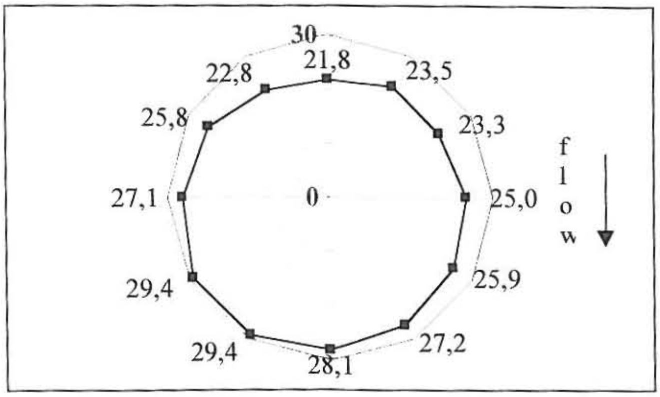

Fig. 10: Vertical displacements of the generator brake bases

TABLE 1: Summary of the Measurements

Measurement	Before correction	After correction
Upper lip support rings unevenness	6.4 mm	0.2 mm
Lower lip plate unevenness	3.6 mm	1.0
Discharge ring ovalling	14.7 mm	3.3 mm
Runner/discharge ring eccentricity	9.2 mm	1.7 mm
Runner/discharge ring minimum diametrical gap	4.5 mm	12.0 mm
Generator stator unevenness	6.2 mm	0.8 mm
Generator brake bases unevenness	7.60 mm	0.8 mm

The Table 2 presents the estimated mean annual vertical expansion rate at different levels of the structure, based in the mechanical measurements and taking into account the rock foundation level (el.199 m) and the time of operation (19 years). One can see that in the same level the displacements varies as much as 41%. The mean vertical expansion rate is in the range of 38 $\mu\varepsilon$/year between el. 226 m and 232 m (spiral case roof) to 50 $\mu\varepsilon$/year between el. 222m and 226 m (spiral case). The vertical expansion measured in the unit 3 by a wire extensometer located at the right side of the spiral case , between el. 215 m and el. 232 m, is 40 $\mu\varepsilon$/year .

TABLE 2: Vertical Displacements and Expansion Rates

Elevation (m)	Vertical displacements (mm)			Annual expansion rate
	minimum	maximum	average	($\mu\varepsilon$/year)
222 (Lower lip base)	15.9	19.5	17.7	40
226 (Upper lip base)	17.8	25.2	21.5	42
232 (Generator brakes)	21.8	29.4	25.8	41
From el. 222 m to el. 226 m				50
From el. 226 m to el. 232 m				38

CONCLUSION

The accomplished rehabilitation services allowed the return of the power generating unit to the network in a favourable condition to operate together with the AAR for a period of approximately of 15 years without needing other similar interventions. The measurements conducted in the rehabilitation process provided valuable information for the knowledge of the expansion within the power house structure.

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