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Evolution of the plug of two-phase flow during the turbine starting of the Coo-2 hydroelectric power station

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Abstract

In order that the Coo-2 storage hydropower station could uphold the electrical network rapidly, the owner plans to modify the turbine starting operation, to leave the wheel running in the air and to open the valve and expel the plug toward the downstream reservoir with the result of two-phase transient and unsteady flow. The study describes the effects of the outflow on the holding of the turbine, the draft tube and pipes. Three approaches have been achieved: by computation, scale tests and site tests. The paper will present the most characteristic results of those studies.
For instance, we note there is a relationship between the evolution of the air pocket, after opening of the control valve and :

- the degree of valve's opening
- the speed of opening of the control valve.

A more advanced study of void fraction and velocities of bubbles, with optical probe, is in progress.

1 Introduction

The hydroelectric storage hydropower plan of Coo-Trois-Ponts of ELECTRABEL located in the Belgian Ardennes, has a power of 1.100 MW about with 6 Francis turbines, 3 of 160 MW and 3 of 205 MW, head varying between 230 to 275 m. The figure 1 gives a schematic view of the plan.
At first, 3 minutes were needed to start in fully automatic operations to supply power to the trash rack from 0 to 100% , now the starting operation time has been reduced to less than 2 minutes. In view to sustain the primary network in a electrical-energy European market, it appeared interesting to study the possibility

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of very short starting, of the order of 30 seconds. The present process consists in starting the wheel-turbine (figure 2) from zero to its nominal rotating speed in water. The project to take under consideration is to operate the turbine as a motor or compensatory synchronised on the network permanently but unwatered with compressed air in order to reduce losses.

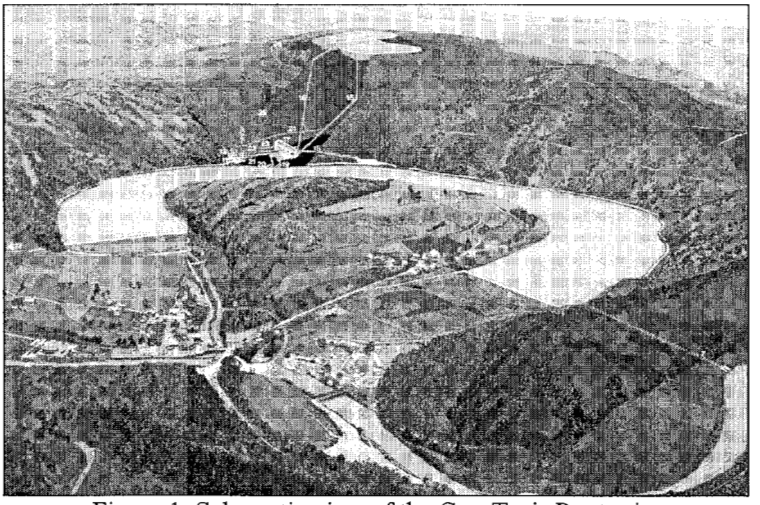


Figure 1. Schematic view of the Coo-Trois Ponts site

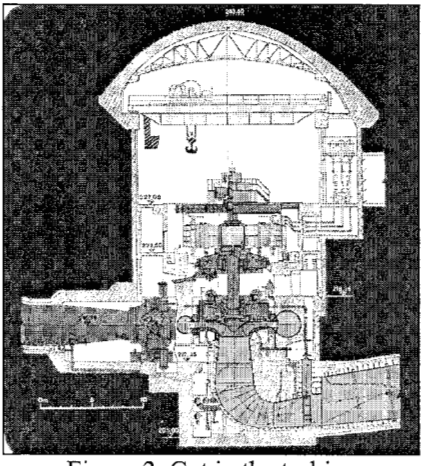


Figure 2. Cut in the turbine

In case of energy demand, there will be a fast opening of the gates (spherical valve and wicket gate) to allow the turbine to shift from motor or compensatory operation to generator and, at the same time, to push the air pocket downstream in the draft tube, pipes and the downstream reservoir. The new two-phase flow

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will be essentially transient and not homogeneous, owing to the presence of air in water.
The present study will try to evaluate the effects of the outflow on the holding of the turbine and the draft tube and on the connecting pipes close to the downstream reservoir.
Three different approaches have been achieved:

- Computation: a modelling of the unsteady water outflow is performed by a numerical model of the transient flow with variable time opening.
- Scale tests: hydraulic scale models have been achieved in transparent Plexiglas to identify and measure the main characteristics of the water flow and the air pocket pattern.
- Site tests : measurements of vibration, pressure, opening of valves and turbine power were performed on the site for various starting time of the turbine.

2 Numerical model

The numerical modelling of the unsteady outflow is achieved for the site of Coo-2 as sketched in the diagram in figure 3.
The main features of the site are the following:

- upstream maximal level: 507,01 m
- downstream minimal level: 233,75 m
- total nominal discharge: 3*96 = 288 m³/s
- the upstream tunnel was constituted of 3 sections AB, BC, CD of lengths and equivalent diameters.
- downstream tunnel EF, length 296 m
- hydraulic resistance coefficient supposed identical for all sections: f = 0,0096
- trash rack in G, middle of EF.

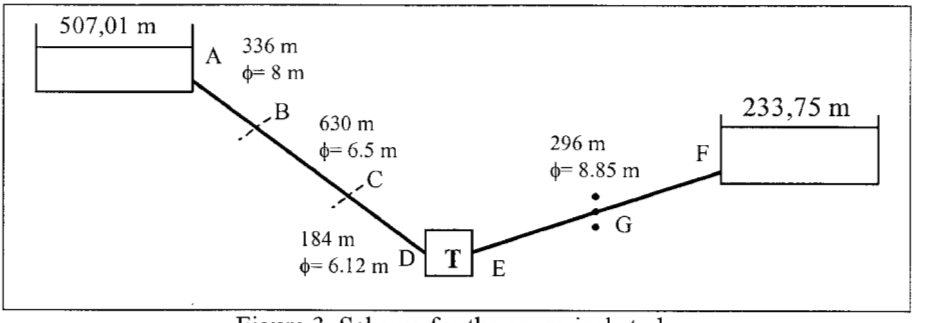


Figure 3. Scheme for the numerical study

For a ratio between surface/total surface equal to 0,28 (value considered by LEVIN for the majority of French power station) Idel'Cik [3] indicates a coefficient of head loss of the trash rack equal to 0,5. The computation of

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unsteady outflow generated by the opening of the valve was performed with the method of characteristics (integration of equations to the partial derivatives of hyperbolic type) that:

- requires the previous knowledge of the speed of overpressure and depression waves;
- requires the subdivision of the pipes of hydraulic circuit in order to respect the Courant criteria.

Taking account of these imperatives, we substituted for the real site of Coo-2, an ideal one that essentially differs by some of the following points :

- the total discharge of 3*96 = 288 m^3/s is supposed to fully pass by only one turbine and not three,
- the downstream tunnel is supposed to be a single tunnel EF and not to divide in two, near the reservoir downstream,
- the numeric simulation is done with a single-phase fluid, the influence of the air pocket will be the object of the modelling tests.

We chose 13 sections whose length gave us a celerity that correspond quiet well to the value, supposed constant, adopted by the BECA office (the designer consultant office), namely: a = 1360 m/s.
The time of opening of the valve will be the variable parameter and will allow the process of various simulations. It has been chosen from 1 to 10 seconds. In the modelling, the outflow was computed during the 15 seconds after the opening.
Places for which we raised variations of pressure are the trash rack and the turbine. Results are summarised in the diagrams that follow.
In these diagrams, the heights h corresponds to the piezometric head. The elevation of the turbine is 215,75 m and the elevation of the trash rack 227,37 m. As an example, the figure 4 shows the piezometric head as a function of the time upstream of the trash rack during the 15 seconds after to a 10 seconds opening.

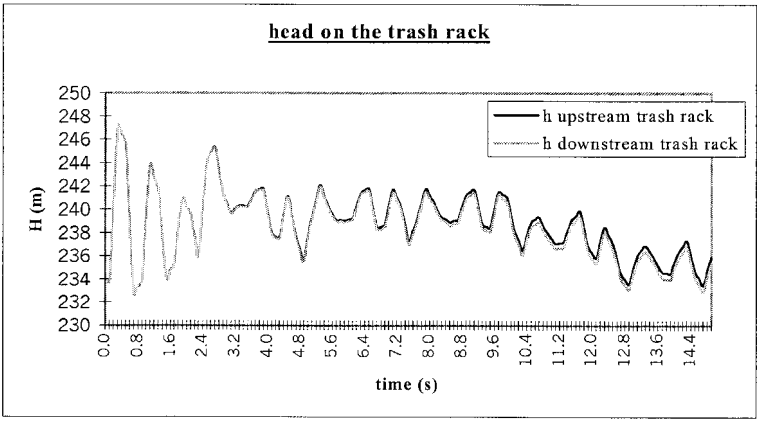


Figure 4. Upstream and downstream head of the trash racks

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The behaviour of the trash rack is best summarised in figure 5 which shows the pressure as a function of the opening time of the gating.
The piezometric head upstream of the trash rack for the permanent outfow (toward which unsteady outflow tends after a theoretically infinite time) is 234,50 m.

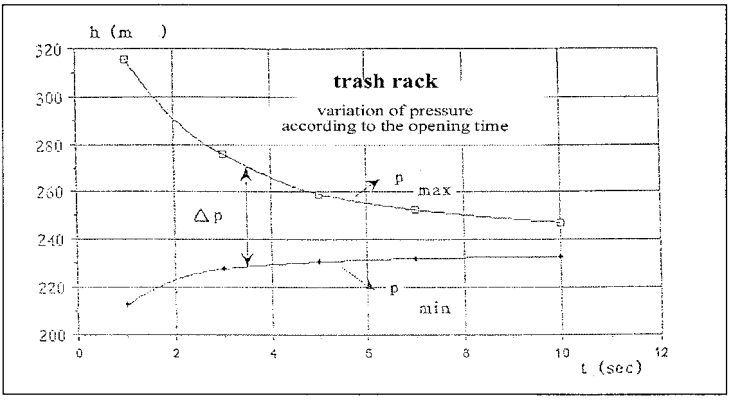


Figure 5. Pressure variations on the trash rack according to times of opening

3 Modelling by scale tests

3.1 First scale model

A first model (figure 6) was achieved in transparent Plexiglas in order to visualise the outflow of air/water flow. It essentially included:
- a pump centrifugal P simulating the upper basin
- a main stop valve corresponding to the spherical valve
- a control valve representing the gating
- a transparent vertical pipe, of approximate length 1 m, of interior diameter 32 mm, including a hole of compressed air injection to its higher part
- a transparent pipe with a slope of 10%, a diameter of 32 mm, simulating the tailrace tunnel and including a trash rack in expanded metal
- the downstream basin.

The manoeuvre of simulation consisted in injecting, control valve closed, a plug of compressed air whose length could vary at will.
The evolution of the air plug, after the opening of the flow-regulating valve, depends:
- on the degree of opening of the stop valve,
- on the speed of opening of the control valve.

A slow opening of the control valve gives rise to an outflow where the plug of air is subdivided in an isolated bubble rosary lodged to the generating superior of the tailrace tunnel.

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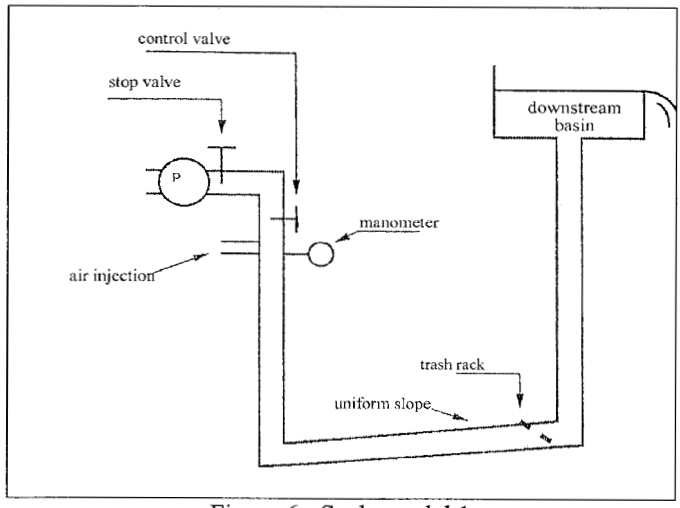


Figure 6: Scale model 1

A fast opening, even though the evolution of the outflow is more difficult to follow visually, seems to indicate the maintenance of the initial shape of the air plug.
A simultaneous and adequate manipulation of stop valves and control valves permits, thanks to the transparency of ducts used, to transport a liquid discharge, the plug of air having split up in isolated bubbles, but captive in the vertical duct.
The passage of the air plug, in fast opening case, to the place of the trash rack, doesn't permit any conclusion about the impact of a possible waterhammer.
We must underline that the model has not been achieved on the prototype scale: information is solely qualitative order and no quantitative (to satisfy, for example, to the law of Reynolds similitude would have led to impracticable velocities in model, if we wanted to use the same fluid transported). It is noted however that the average velocities achieved in the model tunnel correspond to those of the prototype tunnel.

3.2 Second scale model

To approach the existing reality, a second model (Figure 7) was achieved, essentially including the 3 turbines with a draft tube and leading on a common collector.
The operating mode is similar to the one achieved in the first model, to namely: partial regulation of the total discharge by opening of the stop valve

a) closing of the control valve 1 and injection of compressed air
b) opening of the control valve 1
c) opening of the control valve 1,repetition of the phases b) and c) while changing:
   d) the time of opening of c)

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e) the total discharge, either by
   f) other opening of a)
   g) opening of regulation valves 2 and /or 3

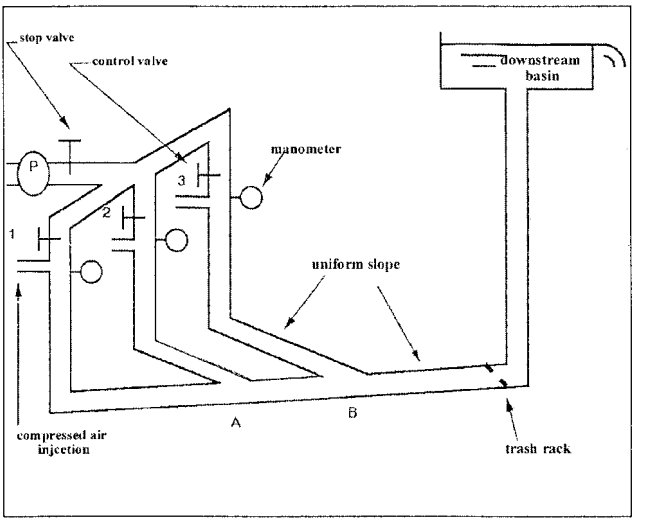


Figure 7 : Scale model 2

The conclusions are :

- the dissociation of the air plug in isolated bubbles depends on the speed of opening of the control valve;
- Valves 2 and 3 being opened or closed either, the fast opening of valve 1 provokes an increase of pressure at the junction A and B of around 80 cm;
- if valves 2 and 3 are closed, the fast opening of valve 1 provokes an increase of pressure of 50 cm to the trash rack;
- if valves 2 and/or 3 are opened, the fast opening of valve 1 provokes an increase of pressure of 30 cm to the trash rack.
- Whatever is the speed of opening of the control valve, the plug of air never has tendency to go up again toward turbines 2 and 3.
- The impact of the air hunt on the working of the two neighbouring turbines is analysed by the next procedure: Valves 2 and /or 3 being opened, they give discharge Q_2 and Q_3 (dependent of the available loads and losses of load provoked); pressures indicated on manometers 2 and 3 are of the order of 20 m.

After opening of the valve 1, the passage of the air plug to the junction A and B provokes an increase of pressure that is not caused by a possible waterhammer however. We record pressures of the new regime, pressures that don't absorb themselves with time contrary to a waterhammer.

Finally, we will notice that terms "slow" and "fast" opening translate the physical process further that the comparison with the return time put by the wave of overpressure-depression from the valve until the reservoir downstream. Indeed, a

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rate of the order of 1200 m/s, on a circuit of 10 m (model), means that an opening achieved for example in 0,2 second, cannot be qualified of fast: (t = L/a = 10/1200 = 0,008 <0,2! !)

3.3 Third scale model

Currently, a third model is to the survey. Conducts of 100 mm of diameter permit to disregard the tensions of surface. Indeed, according to Hager [2] both viscosity and surface-tension effects can be neglected provide that the pipe diameter is larger than 100 mm and only are water and air are involved.
This circuit is represented in figure 8.

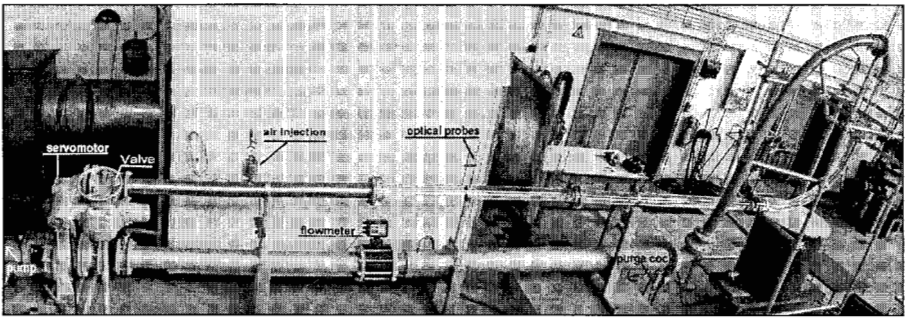
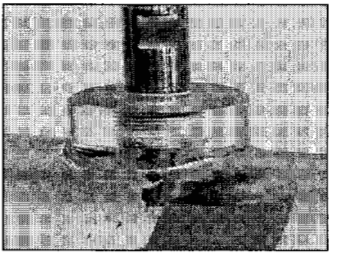


Figure 8 : Scale model 3


Fig 9. Flow on an optical probe

Three optical probes whose position varies in the horizontal and vertical parts of the conduct permit to characterise the distribution of the phases, speeds and diameters of bubbles as well as their number (Figure 9).
The floodgate control automated by an electric servomotor permits us to change the time of floodgate's operation of a systematic and constant way.

4 Modelling by site tests

Tests aimed to verify if a turbine of Coo could answer quickly to a demand of power of the network. When the group is pumping, it is very easily and quickly relieved.

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There remains therefore the problem of its reaction time when the group is to the stop: it needs a little less than one minute to take the parallel then it reaches its full head in about twenty seconds. If the group is in compensatory turbine, it needs 75 seconds to begin to provide the power. Tests consisted therefore in testing possibilities to accelerate the passage of compensatory turbine to turbine and to measure strains inflicted on the group and the trash rack of the lower basin.
Measures of pressure, of position of floodgates, strains, vibrations and cavitation (signal provided by Voight), were achieved in the cave and to the downstream basin [4] (Figure 10).

The following conclusions can be reached:

- Measures show that the passage of compensatory turbine to turbine, without submersion of the wheel doesn't provoke a greater strain to the normal starting. The main fear concerning the passage of the air bubble in trash racks of the intake of the lower basin proved to be vain, given that this bubble is nearly completely left by the trash rack of cofferdam, the rest escaping by holes situated in the roof of the water hold.
- Variations of pressure and vibrations to the main trash rack are comparable at the time of a starting or a passage of compensatory turbine to turbine, with or without submersion of the wheel.
- The passage of compensatory turbine to turbine can be achieved in 36 seconds instead of the 75 seconds in the sequence with submersion.

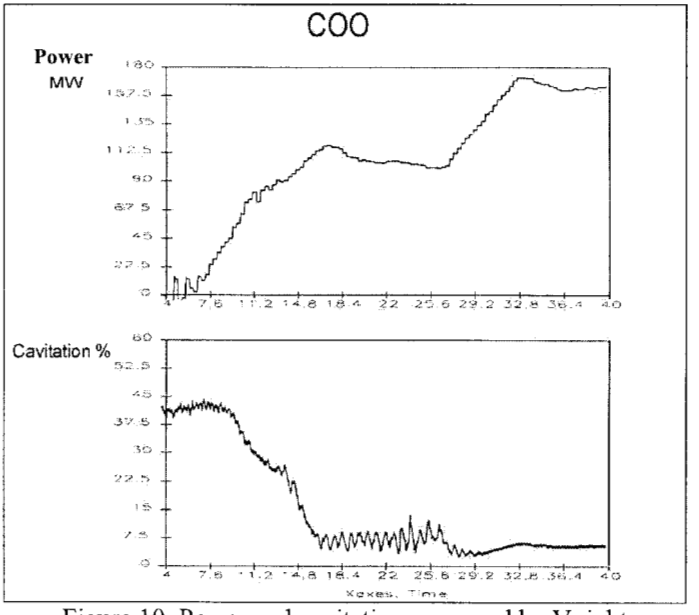


Figure 10. Power and cavitation measured by Voight

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5 Conclusions

Following these studies, several important findings can be summarised as follows:

- The feasibility of the turbine quick start is acquired,
- The present system of floodgate opening is one of brakes to a fast manoeuvre,
- The observed out-flow doesn't have features of a waterhammer,
- There is good general agreement between the numeric studies, the study on the scale model and measures in situ,
- The detailed information about the behaviour of the air bubble, its out-flow and its dividing thereafter in the draft tube, pipelines and the other works,
- Phenomena of shocks from the fragmentation of the air pocket can have not been put in evident in these studies,
- A complementary survey is necessary in order to analyse in detail the behaviour of the air pocket and its fragmentation.

This study will permit better understanding of the transient two-phases flows and the behaviour of bubbles and the plug, in the oil industry and understanding of problems in the interconnecting piping, for instance when a change of liquid is performed in the pipeline system.
The survey should determine how long the grid and the pipe will resist the air pocket and these strains.

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