Ultrasonic flow measurement at the Genissiat hydropower plant

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Introduction

Precise knowledge of the turbined flowrate at the Génissiat hydropower plant on the Rhône River is fundamental for managing and optimizing the plant's production and for controlling that the minimum flow conditions are met for the cooling of the Bugey nuclear power plant located downstream. Six Francis type units equip the Génissiat hydropower plant with a nominal head of 65 m and an installed capacity of 420 MW. The flowrates of the different units are not identical since the characteristics of the turbine-runners are different. It was therefore decided to equip all the units with an acoustic flow measurement system between 2008 and 2011. The system consists of 8 acoustic paths in 4 measuring planes according to the IEC41 standard. The diameter of the pipe is 5.75 m, the average flowrate is around 100 m^3/s, i.e. an average velocity of around 4 m/s.

In order to validate the ultrasonic flow measurements, two measurement campaigns were carried out in 2010 and 2012 by intercomparison with aDcp (Acoustic Doppler Current Meter) discharge measurements. Simultaneous deployment of huge numbers of aDcp gauging (26 in 2010, 37 in 2012) on stable flow discharges allowed estimating an uncertainty of the ultrasonic measurements in the range of one percent. More recently, in order to better analyze and understand the results of the velocity measurements of each acoustic path, two CFD models have been carried out. The first model represents the upstream reservoir and provides a better understanding of the feeding conditions at the intake of each unit. The second model represents the water intake and penstock. It is used to determine numerically the velocity at each acoustic path in normal feeding condition and with a non-symmetrical feeding condition at the upstream intake (simulation of debris accumulation on grids or impact of the bathymetry).

First, the article describes the ultrasonic flow measurement system implemented on site, the maintenance operations of the system, and the verification procedures that have been put in place to check the flow measurement values.

Then, the article presents the results of the inter-comparison study with aDcp measurements, the analysis of the measurements of each acoustic path and the contribution of CFD simulations. All these analyses lead to the validation of the acoustic flowrate measurements for each unit with about one percent uncertainty and thus allow optimizing the operation of the Génissiat power plant.

Finally, the article describes the unit efficiency measurement campaigns carried out since October 2019. The results show that there are noticeable differences in the “efficiency Vs flowrate” relation for each unit, thus making it possible to adapt its management in order to optimize the total production of the plant.

1. Context and objective

CNR holds the concession of the Rhone for hydroelectricity production, river transport, and agricultural use, and it is also France's leading producer of exclusively renewable energy. Its perimeter of operations extends from the Swiss border to the Mediterranean Sea (cf.fig.1). Founded in 1933, CNR's first hydroelectric development scheme was brought onstream at Génissiat in 1948. Following that, CNR constructed 18 other development schemes, the last of which was commissioned in 1986.

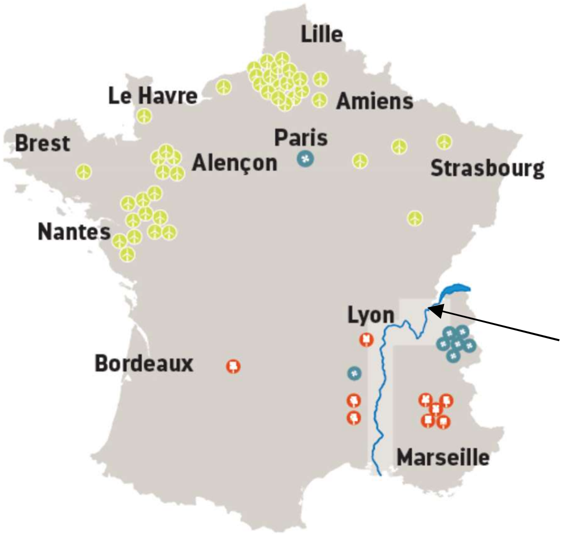
The Génissiat hydropower plant is also that having the highest head, approximately 65 m in comparison to an average head of about 20 m for the other plants. Its six Francis turbines with a unit capacity of about 110m^3/s generate 420MW. The water intakes of these turbines are supplied by penstocks with a diameter of 5.75m, providing a velocity close to 4m/s at nominal discharge.

Precise knowledge of the discharges passing through the turbines is essential to:

- Optimize energy production by knowing the absolute efficiency depending on the discharge,
- Ensure efficient management of the volume flowing out of the reservoir,
- Guaranteeing in total safety the minimum flowrate value to cool the nuclear power plant located 120km downstream.

Historically, flowrates are calculated using equations of gate/head positions established using scale models and completed by current meter measurements. The machines have aged since raising the issue of the pertinence of the flowrate values resulting from these experimental equations. For several decades, the total plant flowrate was compared to classical gauging carried out further downstream. The consistency between the plant flowrate and the gauging allowed concluding on an uncertainty of about 5%.

In 2008 CNR decided to equip all the turbine units of the Génissiat plant with a system that gave the flowrate with an uncertainty of about 1% to optimize the plant's management. This document presents the procedure implemented, its results and the perspectives.



Génissiat
hydropower plant

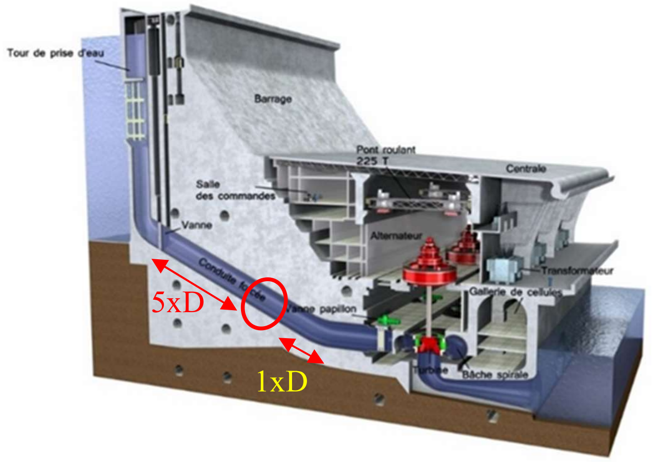
Fig. 1: Localization of the Génissiat hydropower plant.

2. Method

2.1 Ultrasound sensor in the penstock

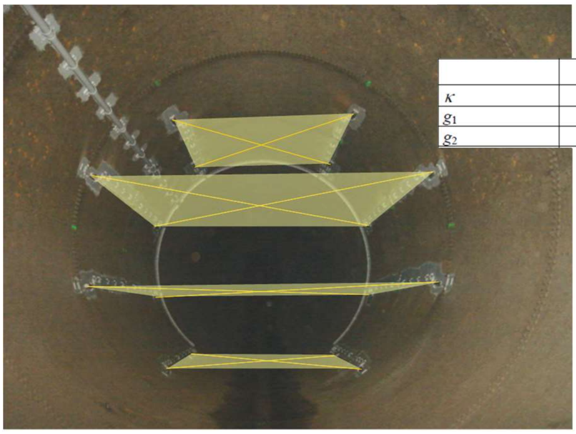
Taking into account the typology of the penstock between the water intake and the Francis turbine unit, CNR chose ultrasound time-of-flight (ToF) sensors. The optimal measurement zone is located five times the diameter in relation to the upstream elbow and 1 x the diameter in relation to the disturbance linked to the downstream elbow (cf. fig.2)

Four measurement planes were instrumented to obtain an uncertainty on the flowrate of less than 1% according to standards IEC41 [1] and ASME PTC 18-2002 and works on the OWICS [2] method that allow taking into account the real position of the sensors (cf.fig.4). Each measurement plane is equipped with 2 paths crossed at about 45°. They are 4.7m or 7.4m long depending on their position. Since the penstock is embedded in the concrete of the dam, the sensors (200kHz) were fixed directly on the inside of the penstock via welded plates. The cables are connected to the data acquisition center via a steel sheath also fixed to the interior of the penstock (cf. fig.3).



Distance Amont / Aval	Application IEC41	Avec optimisation[1]
1D / 1D	± 2.18 %	± 1.02%
5 D / 1 D	± 1.26 %	± 0.82 %
10 D / 1 D	± 0.62 %	± 0.53 %
50 D / 1 D	± 0.42 %	± 0.26 %

Fig. 2: Left, position of the US sensors in the upstream penstock – right, reduction of uncertainty according to OWICS.



$$Q = \frac{D}{2}\sum_{i=1}^{n} W_i \cdot \overline{v_{ai}} \cdot \sqrt{D^2 - 4d_i^2}$$

	Gauss-Jacobi IEC 41	OWICS[7]
κ	0,5	0,6
g_1	0,0981748	0,0900812
g_2	1,5707963	1,5133647

$$W_1 = \frac{g_1 D^2 (d_3 + d_4 - d_2) - g_2 d_2 d_3 d_4}{(1 - 4d_1^2/D^2)^{\kappa}(d_1 - d_2)(d_1 + d_3)(d_1 + d_4)}$$

$$W_2 = \frac{g_1 D^2 (d_3 + d_4 - d_1) - g_2 d_1 d_3 d_4}{(1 - 4d_2^2/D^2)^{\kappa}(d_2 - d_1)(d_2 + d_3)(d_2 + d_4)}$$

$$W_3 = \frac{g_1 D^2 (d_1 + d_2 - d_4) - g_2 d_1 d_2 d_4}{(1 - 4d_3^2/D^2)^{\kappa}(d_3 - d_4)(d_1 + d_3)(d_2 + d_3)}$$

$$W_4 = \frac{g_1 D^2 (d_1 + d_2 - d_3) - g_2 d_1 d_2 d_3}{(1 - 4d_4^2/D^2)^{\kappa}(d_4 - d_3)(d_1 + d_4)(d_2 + d_4)}$$

Fig. 3: Four planes with two paths crossed, seen from upstream going downstream.

	Erreur totale	
	Application IEC41	Avec optimisation
Erreur d'intégration	±1,2%	±0,8%
Erreur de positionnement	±0,3%	±0,1%
Erreur de géométrie	±0,2%	±0,1%
Erreur électronique	±0,1%	±0,1%
Total $\sqrt{\sum \varepsilon_{i0,95}^2}$	**±1,26%**	**±0,82%**

Fig. 4: Reduction of uncertainty with OWICS optimization for 4 planes equipped with 2 crossed paths.

The installation is accessible on a secured computer network that allows:

- saving all the velocity, temperature and flowrate data derived from the measurement system. Recovering elementary velocity and temperature data is vital for counter-checking the data and recalculating it if an anomaly is detected;
- very useful remote control for maintenance operations.

2.2 Validation when starting operations

CNR wanted to equip the first penstock and obtain initial feedback before equipping all the turbine units (cf.fig.5). The works were performed over about three to four weeks.

Fig. 5: Genissiat dam seen from upstream.

The service company (Hydroservices) carried out its own tests on the installation:

- check of cable impedances: verification of insulation quality;
- check of sensor impedances: verification of sensor status and its connection with the cable;
- check of acoustic signal quality: verification of the orientation of the sensors and the calibration of the signal parameters;
- measure of water flowrate without flow;
- measure of flowrate at nominal flow.

In 2008, G2 was the first turbine unit to be equipped. A series of ADCP gauging ([3], [4], [5], [6], [7], [8], [20]) operations immediately downstream of the plant permitted measuring the flowrate with a system external to the installation and independently of the ultrasound sensors.

Given the very good consistency between the ADCP gauging and the penstock sensors (cf. §3), it was decided to instrument the five other turbine units between 2010 and 2011 during maintenance operations that had already been scheduled.

In 2010 and 2012, CNR, in relation with the GDH (Groupe Doppler Hydrometrie) organized an ADCP inter-comparison downstream of the Génissiat hydropower plant to improve knowledge of the uncertainty on the river gauging using ADCPs for different flowrate conditions. 26 ADCPs in 2010 and 37 in 2012 measured the flowrate simultaneously downstream of the plant.

The duration of the stages was set at two hours to guarantee the stability of the flow and allow the comparison of gauging downstream of the plant with the total flowrate leaving it. The plant was operated manually with the elimination of everything capable of causing a variation of the non-controlled flowrate. Thus, only the head could cause the flowrate to change. The gate positions were stable throughout the duration of the measures. The primary regulation of frequency was inhibited. The passage from stage N to N+1 was done by starting a single turbine unit by conserving the others in the same state as during the previous stage.

The flowrate stages were performed only with the instrumented turbine units. Thus, in 2010 stages from 110 / 220 / 330 and 440 m^3/s were performed with G1 / G2/ G4 / G6. In 2012, turbine units G1 / G3 / G5 were used with flowrate stages of 220 / 330 / 440 /550 m^3/s.

This measurement protocol therefore made it possible to compare:

- The total flowrate of the plant via the sensors in the penstocks with the total flowrate gauged downstream;
- The flowrate of a turbine unit generating an increase from stage N to N+1 with a variance of the gauged flowrate between stage N and N+1 by integrating the variation of the flowrate generated by the variation of the head.

The underlying issue for the period 2008-2012 was to validate a measurement system in the penstock within 1% precision with equipment usually precise to within 5% when used in good conditions.

The progress in mastering ADCP gauging, in particular its uncertainty, had improved considerably with the inter-comparison. Indeed, the uncertainty on the gauging resulting from the mean of all these measures was significantly reduced in comparison with a single ADCP used in classical river gauging. Given the teams in place in 2010-2012, the uncertainty at 95% on the value of the downstream gauging resulting from a large number of ADCPs and transects can be estimated at 3% (cf.fig.6).

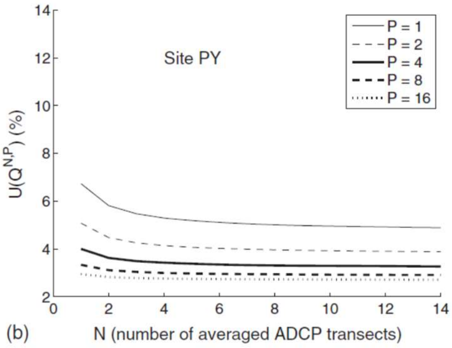


Fig. 6: Uncertainty on ADCP gauging as a function of the number of team members and the number of transects.

These initial tests using gauging were performed to validate the total flowrate supplied by the ultrasound sensors of the installation equipped with 8 measurement paths when the equipment was delivered on site.

2.3 Reliability through time

The reliability of the flowrates then had to be verified through time. Gauging with a large number of ADCPs is occasional since it’s requesting a lot of resources. The analysis of velocities with paths through time also permits detecting anomalies that could considerably deteriorate the uncertainty on the flowrate obtained with the ultrasound sensors in the penstocks.

In standard conditions, the choice of the zone to be instrumented had to permit, according to expert opinion, obtaining a flow without disturbance and thus propitious for flowrate measurements precise to within 1%. The analyses of the elementary velocities at each path must make it possible to identify the turbine units in which the flow is hydraulically “clean” and others where the flow risks being disturbed. This analysis must be done, if possible, before the installation of the sensors by CFD modeling ([10], [11], [12]). This analysis is used to verify the pertinence of the flowrate estimation calculated with the acoustic paths of the CFD model whatever the hydraulic disturbances observed. In the case of a variance between the flowrate value introduced in the CFD model and that resulting from the estimation as a function of the velocities of the acoustic paths of the CFD model, it might be advantageous to increase the number of measurement paths.

This analysis also permits checking the possible impact of the loss of measurement paths on the flowrate uncertainty. As will be seen in §3, the flow in the penstock upstream of certain units at the center of the plant is hydraulically clean and will give a flowrate to within 1% even if certain paths are defective. Conversely, the units near the banks present a disturbed upstream penstock flowrate and the possible loss of a measurement path can considerably deteriorate the precision of the flowrate.

3. Results

3.1 Internal tests of equipment

The internal tests were declared valid for the electricity and temperature measurements as well as those with null flowrate when the penstock was filled with water with the unit stopped.
According to the penstocks, the leakage flowrate, everything being closed elsewhere, was between +/-300l/s for 5 units out of 6 and close to 1m^3/s for one unit.
All the temperature measurements varied between +/-0.5°C. The temperature of the water via the acoustic system was compared to an external transducer PT100. The variance was lower than 1°C.
Sometimes some paths presented erratic temperature peaks that announced the aging of the connectors or cables.

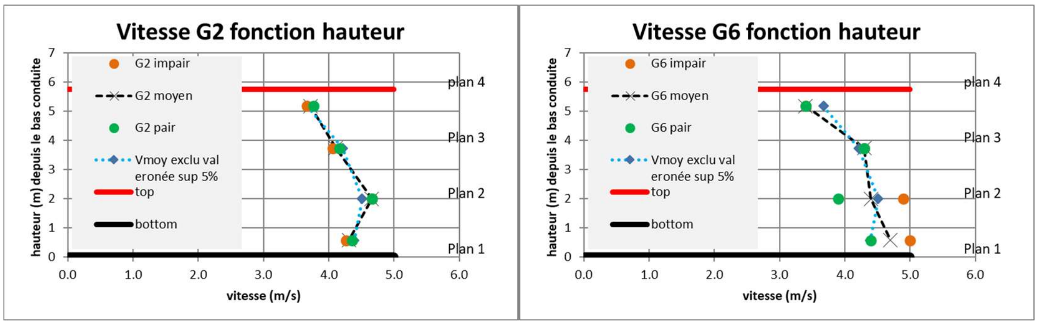
At this stage the service company guaranteed the reliability of the installation with an uncertainty on the flowrate value of about 1%. We will see that these internal tests were necessary but not enough, cf. § 3.4.

Indeed, tests independent of the installation permitted at least showing the good consistency of the measures, or, on the contrary detected errors on the flowrate value supplied by the ultrasound system in the penstock.

3.2 Impact of the number of paths on the uncertainty on the flowrate

It should be noted that the tests done using gauging (cf §3.3 et 3.4) downstream led us to reinforce the internal tests on the reliability of the flowrate supplied by the ultrasound system. We analyzed the vertical profile of the velocity by unit (cf.fig.7) to observe that.

- The units of the center (G2/G3/G4) had a homogenous profile: for a given flowrate, the velocities by plane were homogenous, parallel to the axis of the penstock and the same from one unit to the other.
- The units close to upstream singularities (banks, bathymetry) had velocities non-aligned according to the penstock. 2 paths of the same plane were not necessarily identical. The vertical profile of the velocity can differ from the vertical profile of the units at the center. This was the case of units G1 / G6 and to a lesser extent unit G5.


Vitesse G2 fonction hauteur

Vitesse G6 fonction hauteur

Fig. 7: Uncertainty on ADCP gauging as a function of the number of team members and transects.

This observation raised two questions:

- Were 4 measurement planes enough to guarantee an uncertainty of about 1% in the case of a flow non-aligned according to the penstock (G1/G5/G6)?
- What was the deterioration of the uncertainty in the case of a loss of one or more paths for a unit at the center and at the bank side?

3.2.1 CFD modeling

A CFD model of the reservoir was built (Optifluides) to observe the flow conditions at the approach of the water intakes. This model (cf.fig.8) allowed observing a flow well-distributed at the grids of the water intakes for the units at the center: G2/G3/G4. On the contrary, the flow close to the water intakes for the units close to the banks was not uniformly distributed.

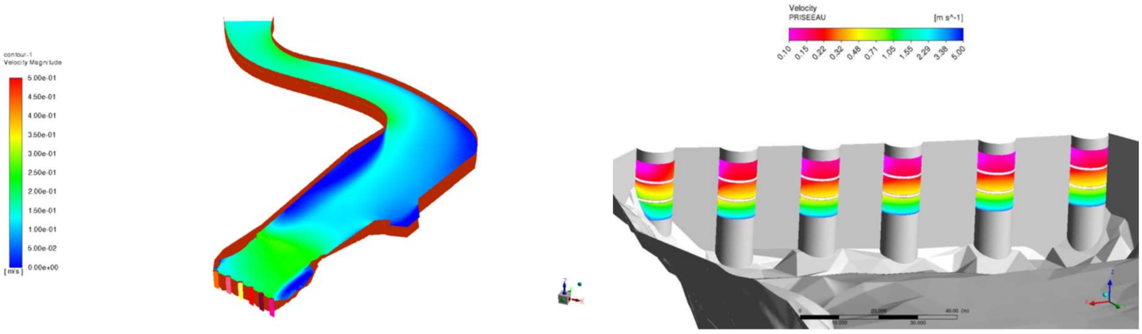


Fig. 8: CFD model of the overall structure for the flow conditions upstream of the water intakes – on the right zoom on a water intake.

A CFD model of the penstock from the water intake to immediately upstream of the turbine was built (cf.fig.9) to determine the flow conditions at the section measured by the ultrasound sensors. It was observed that the flow was well aligned according to the penstock if it was fed uniformly by the water intake. This was the case with the units of the center: G2/G3/G4. For the units at the banks (G1, G6) the specific bathymetry upstream of the water intakes generated a turbulent flow along the entire penstock.

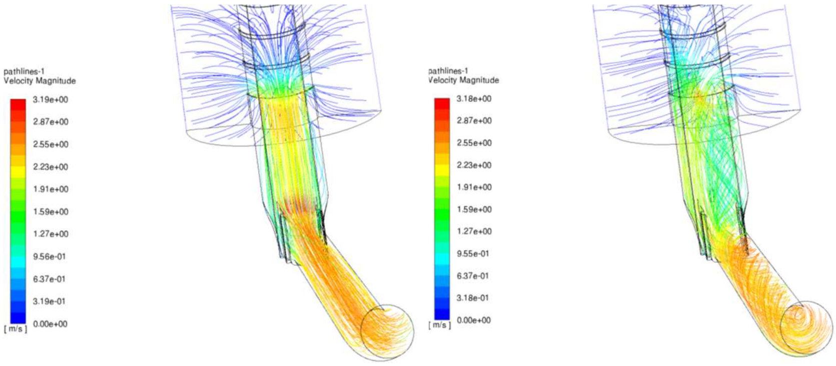


Fig. 9: CFD model of the penstock – left, the flow aligned along the penstock – right, a turbulent flow in the penstock.

The velocities at the 8 acoustic paths were extracted from the CFD model. The application of the OWICS formula was used to calculate the flowrate in the same way as the ultrasound system was used on the site. This flowrate was compared to the flowrate injected in each modeled penstock. The variance remained lower than 1% whatever the disturbance imposed at the water intake. Thus, the 4 measurement planes ensured an estimation of the flowrate to within less than 1%.

3.2.3 Abnormal mode

The software of the measurement equipment permitted operation in abnormal mode. The aim of the abnormal mode was to continue supplying a flowrate value even in the case of partial loss of the measurement paths. By default:

- A lost measurement path was rebuilt by duplicating the acoustic path of the same plane;
- A loss of the measurement plane, in the case of a failure of two paths of the same plane, was rebuilt using the velocity of the plane diametrically opposite.

Tests of sensitivity to the loss of a measurement path were performed to observe the deterioration of the uncertainty on the measurement as a function of the path lost:

- Less than 1% for the units of the center in the case of the loss of a single path per plane;
- From 1 to 20% variance in the other cases.

Initially, we recovered only the value of the flowrate. Following this observation, we recovered all the velocity measurements of 8 paths per unit in real time in order to qualify the uncertainty on the measure according to the number of paths and the turbine unit concerned. We accepted or refused the value of the flowrate measurement as a function of its utilization. For example, to obtain hydrological knowledge of the basin, we could accept an uncertainty of about 5% whereas to estimate the efficiency of the units, we conserved only the series of flowrates with less than 1% uncertainty.

3.3 External test turbine unit by turbine unit

It is necessary to test the reliability of the flowrate of a turbine unit by gauging downstream of the plant. This is made easier when the hydropower installation allows turbining with only one unit, especially if the head allows storing the surplus flowrate entering. This what was done in 2008 to validate the commissioning of the installation.

Figure 10 shows the consistency of the flowrate between the gauging downstream of the plant and the ultrasound flowrate of G2 of about 1% in both absolute and dynamic values. ADCP transects were applied for four hours while only G2 was in operation.

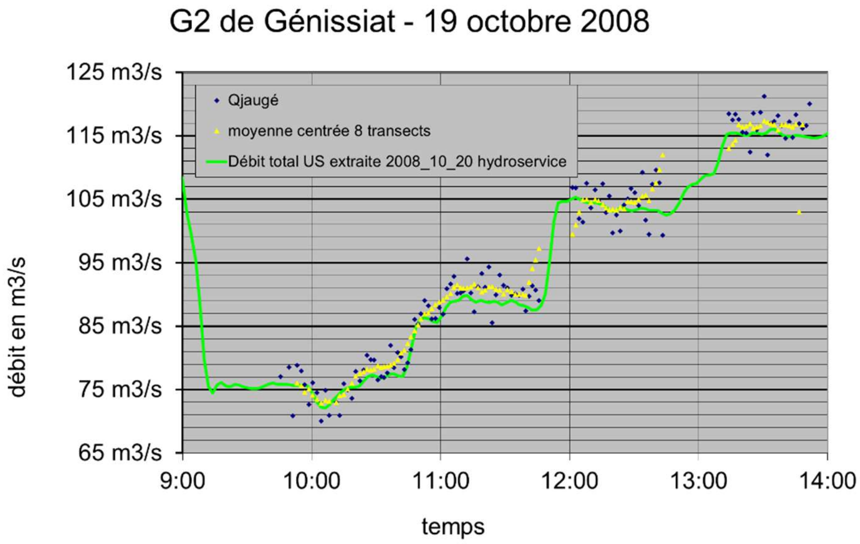


Fig. 10: ADCP gauging downstream (yellow) compared to the ultrasound values of G2.

Given the very good consistency between the ADCP gauging (uncertainty of 5% calculated by the OURSIN software [19]) and the ultrasound flowrate, it was decided to continue the instrumentation with the five other units between 2010 and 2011.

3.4 Multi-turbine tests

This multi-turbine test methodology is interesting when it is not possible to force the whole flowrate via a single turbine.

The intercomparaisons ([9],[14],[15],[16],[17],[18]) of 2010 and 2012 provided the flowrates downstream of the plant with an uncertainty of around 2 to 3%. This allowed comparing the gauging value with that of the ultrasound equipment (on G1, G2, G4, G6).

The first intercomparison of 2010 (cf.fig.11) showed that total discharge gauged flowrates were systematically higher by 4 to 7% than those displayed by the ultrasound installation. These variances were obviously too high given the expected uncertainty of 1% for the ultrasound and from 2 to 3% for the ADCPs.

Total discharge downstream Génissiat compare to ultrasoubd system	13/10/2010	13/10/2010		14/10/2010	14/10/2010	
	Q0	Q1	Q2	q0	q1	q2
Q average of 26 ADCP (m3/s)	222	335	439	118	227	333
1/ ultrasond refernce first analyze (m3/s)	212	317	413	108	211	314
difference ADCP and ultrasound (%)	4.2%	5.3%	5.9%	8.3%	7.2%	5.8%
2/ ultrasond reference after correcting (m3/s)	218	328	429	116	223	327
difference ADCP and ultrasound (%)	1.6%	2.1%	2.2%	1.6%	2.0%	1.7%

Fig. 11: ADCP gauging compared to G2 ultrasound values – first analyze and after correcting

Each stage was performed with the operation of a single unit in relation to the previous stage. Due to the hydrology on the day, it was not possible to turbine the flow with only one turbine. The first stage was therefore carried out with two turbine units, then an additional unit at each stage (cf.fig.12).

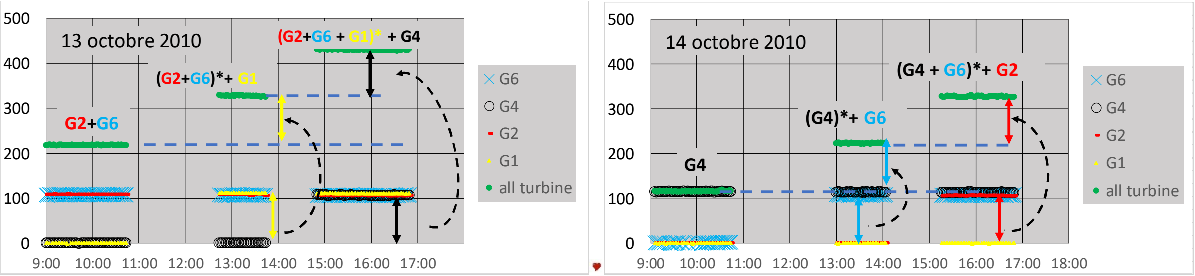


Fig. 12: Each discharge stage built with single turbine to extract ADCP value gauging reference

The variances of flowrates between the stages allowed extracting the flowrate values from the gauges and assigned to the startup of G1 and G4 on 13/10 and G2 and G6 on 14/10. By way of example, flowrate Q_{G1} of G1 during stage "Q_1" (turbine G2+G6+G1) corresponds to the difference in flowrate between Q_1 and Q_{0*}. Flowrate Q0* corresponds to the flowrate of configuration Q_0 (turbine G2+G6) during stage Q_1. However, even when blocking the blade-gate position and other regulating devices, flowrate Q_0 evolved as the head varied (H_1-H_0). Thus, flowrate Q_{0*} was deduced from Q_0 by taking into account the variation of the head, which directly impacts the velocity, since the gate position was stable throughout the measurements:

$$Q_{G1} = Q_1 - Q_0 * \left(\frac{H_1}{H_0}\right)^{\frac{1}{2}}$$

These estimations of turbine flowrates using ADCP led to observing systematic variances with those given by the ultrasonic sensors of 3% on G2 and 7% for G1, G4 and G6. The variance on G2 is compatible with the observations of 2008 whereas those of G1, G4 and G6 were clearly too high with respect to the uncertainty of the multi-ADCP intercomparison by about 2 to 3%.

CNR asked the equipment supplier to verify the entire ultrasound installation by indicating that the variance was too great with the reference gauging, without specifying the values. The analysis carried out by the supplier revealed an error in the programming of the acoustic paths on the new turbines that had been equipped with instruments. This error was explained by the fixing of the sensors so that they projected from the interior of the penstock whereas sensors are usually installed from the exterior of the penstock and project only minimally in the interior section. Therefore, several cm were missing (the thickness of the sensor) from the diameter of the penstock in order to calculate the flowrate. On the other hand, G2 was programmed correctly.

After correcting (cf.fig.11) the programming of the ultrasound sensors, the variances on the flowrates of each turbine unit between the multi-ADCP gauging and the ultrasound gauging were of about 2% for the 4 turbine units used in 2010: G1 / G2 / G4 and G6. Likewise, the total ultrasound flowrate was close to the flowrate gauged to within 2%.

The intercomparison of 2012, carried out using the same protocol as in 2010, involved testing the other units: G1/ G3 / G5. The variances obtained were of about 2% for G1 and G3, and about 5% for G5. For the latter, an analysis is in progress, in particular on the parameters of the processing software (sensor positions, acoustic signal, etc.).

These variances of about 2% increased confidence in the reliability of this equipment in the penstocks for the six turbines instrumented according to the same protocol.

It should be noted that:

- In 2012, the verification done by gauging was a global verification without ensuring the pertinence of the velocity measurements by path. It was not until 2019 that we focused on the pertinence of these values. Indeed, using values to estimate flowrates was exploited to determine the efficiency of the turbines. Thus, it was necessary to be sure of the flowrate values to within 1% (cf. §3.2).
- This methodology of extracting an increase in flowrate using multi-ADCP gauging was used by CNR at Châteauneuf du Rhône in 2009. It showed variances between 1 and 3% in relation to an ASFM reference flowrate on three stages of flowrates (100, 200 and 300m^3/s).

4. Maintenance

This paragraph deals with the main points of vigilance for ensuring maintenance:

- Basis maintenance by analyzing the data with the penstock filled with water,
- Maintenance of equipment inside the penstock, thus out of water.

4.1 Maintenance with the penstock filled with water

Analysis of the data ensures that the installation always provides quality flowrate values. This analysis can be of three types:

- Automatic:
    - ➯ Monitoring the presence of 8 paths;
    - ➯ Monitoring the efficiency of the turbines, estimated with power and the head, both known from other sources;
    - ➯ Monitoring of the water temperature which must be homogenous between all the paths.
- Annual:
    - ➯ Monitoring the impedances of each measurement channel, 16 for each turbine unit, indication of water infiltrating in the connectors;
    - ➯ Monitoring the versions and parameters of ultrasound measurement processing software.
- Punctual:
    - ➯ Multi-ADCP gauging

A variance with known records will therefore be due to a measurement error or a turbine operation problem.

The connection of these measurement systems to a secured computer network permits easier remote maintenance for both CNR's operatives and for service providers located far from the site of Génissiat. This remote maintenance leads to significant time-saving and better intervention conditions, which was especially the case during the Covid-19 pandemic in which social distancing is enforced.

4.2 Maintenance with the penstock empty

The difficulty of maintenance is directly linked to the accessibility of the cables and connectors inside the penstock: as much for testing them as for replacing them. Indeed, all the maintenance operations inside the penstock are linked to other interventions needed for hydroelectricity production. The aspect of measurement is secondary.

The weak point of, these items of equipment is the resistance through time of the cable/sensor connections. The cable and the sensors are generally robust. The least infiltration of water into the connectors risks invalidating the velocity measurements. Rigorous sealing is therefore necessary for these connectors and their future replacement must be planned. Lastly, in the case of failure on a measurement path, we recommend replacing the two sensors (including the connectors) of the path even if only one of the sensors appears to have failed.

At the end of 2020, 5 paths out of the 48 installed will have been replaced, i.e. about 10% of the equipment inside the penstock. Each time, the sensor seemed correct, it was the infiltration of water inside the cables that was the cause of the failure of the ultrasound measure.

For the installation of the sensors, it is recommended to use a rolling scaffold such as that used for the linear inspection of penstocks in the plant. This solution greatly reduces the cost in comparison to the use of fixed scaffolding.

Regarding sensor maintenance, rolling scaffolds can be used if the duration of the maintenance is long enough (a few weeks). When this not the case, it is preferable to weld plates inside the penstock. This solution allows carrying out an intervention with specialized personnel in only a few hours by fixing hooks on the plates provided for this purpose.

5. Estimation of turbine efficiency

The time series of ultrasound flowrates linked to alternator power output and gross head (plant upstream level – plant downstream level permits estimating a time series of gross head efficiency for each of the turbines. The black curve in figure 13 shows the evolution of this efficiency for turbine unit 1 as a function of the flowrate. The black dashes show the dispersion of the efficiency estimations for the period from October 2019 to April 2020. This dispersion integrates the uncertainty on the measure and the possible influence of the head varying from 64 to 68 m. This analysis automatically selects all the minute points on the stability criterion. This automatic analysis is consistent with the punctual tests in a stable situation and the control depicted by the red dashed line.

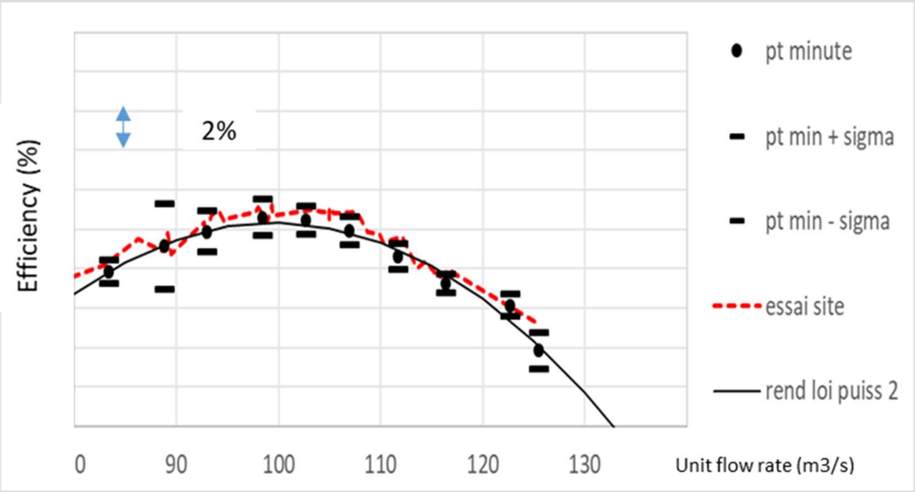


Fig. 13: G1 efficiency (gross head) as a function of flowrate with uncertainty on efficiency.

Figure 14 illustrates the units efficiency (gross head) of the Génissiat plant during the period from October 2019 to April 2020. On the one hand it can be seen that the variances of the efficiency between the turbines are fairly large (variance of about 4% on the optimum efficiency, and still larger when drawing away from these optimums). On the other hand, the variation of the efficiency as a function of the flowrate is also different between the turbines.
At present, the turbines operate over a range of 90-130m^3/s and in equi-distribution of the flowrate.
Thus, it is proposed to change this mode of operation by optimizing the production as a function of the turbine efficiency.

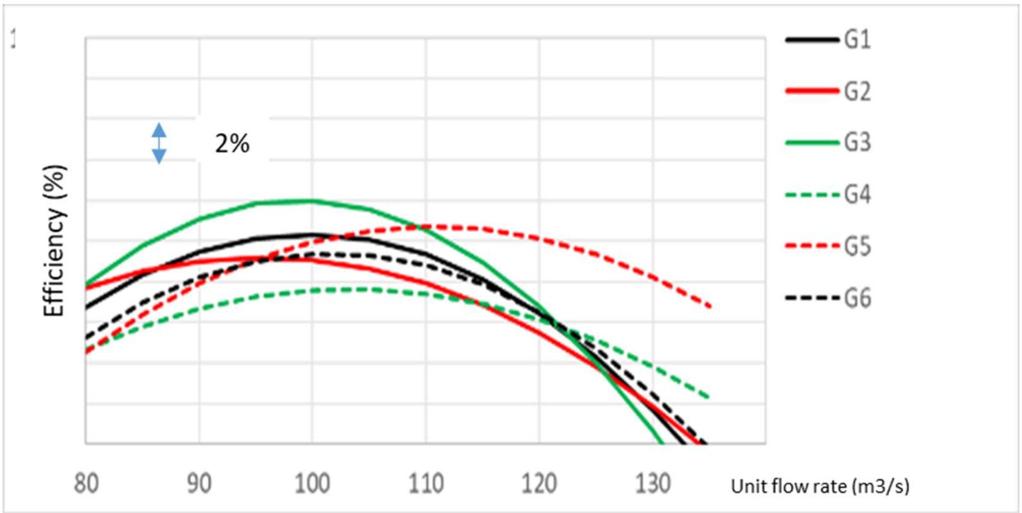


Fig. 14: Efficiency (gross head) of the 6 turbine units as a function of flowrate.

The first flowrate optimization simulations by turbine unit over a constant operating period showed a gain in the region of 10 000 MWh/year (€500k/year considering a mean value of €50/MWh). This gain must be compared to the €800k of investment to equip the 6 turbine units.

6. Conclusions and perspectives

The ultrasound equipment of the six penstocks of the Genissiat hydropower plant provide the flowrate value of all the turbine units in real-time to within 1% provided that the 8 measurement paths are functioning. This value of 1% results from the multi-ADCP gauging and the CFD results.

It is necessary to carry out regular monitoring of the indicators validating the reliability of the installation over time. Those that can be monitored in real time are chosen: number of paths in operation, velocities, temperature, efficiency.

Regarding design, it is necessary to plan the installation of this equipment through using a CFD model that validates the number and position of the acoustic paths, above all due to the lack of alignment at right angles on the penstocks. It is also necessary to plan maintenance operations on the equipment inside the penstock, especially since accessibility is more difficult for maintenance than during the initial works.

In the short term, these measures will be used to optimize the global production of the Genissiat hydropower plant by integrating the efficiency of the turbine units in the choice of flowrate to be turbined in addition to the maintenance criteria already used. This efficiency monitoring should also allow anticipating operating defects and thus optimize the predictive maintenance of the turbine units.

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