FIELD ACCEPTANCE TESTS AT MULTIPURPOSE MAROGGIA SMALL HYDROPLANT: A CASE STUDY

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SUMMARY

The paper presents the check on performance undertaken at Maroggia multipurpose small hydro plant.
The interest of the project is:

- the simplification in measuring procedures in comparison with the international standards, without loosing reliability
- the conception of the plant to make provision for the measurement of the head and flow;
- the tests will be easily repeatable during the life of the plant;
- easy application of the measuring procedures to other similar plants;
- the peculiar multipurpose (fire control) plant.
- continuous monitoring of the flow in open channel pipes to avoid leakage and prevent landslides

1. DESCRIPTION OF THE PLANT

1.1. GENERAL OUTLINE

Maroggia small hydro plant exploits the water resources of three different valleys: Val Laresa(1.3 km^2), Val di Mezzo(0.7 km^2) and Val Vignone (2.7 km^2) and it is located in a lateral valley of the lower part of Valtellina (Northern Italy) about 15 km West of Sondrio. The total catchment area is therefore about 4,7 km^2. The name of the plant derives from the name of a small river, Maroggia, right tributary of the River Adda, the largest right tributary of the River Po. The main characteristics of the plant are the following:

Maximum plant flow rate	0.200 m^3/s
Average exploited flow rate	0.125 m^3/s
Installed capacity	1,400 kW
Gross head	814 m
Expected energy production	6.3 GWh/yr
First kWh produced	16.11.98
Building start-up:	June '97
Construction time	17 months

1.2. INTAKE STRUCTURES

Maroggia small hydro plant is fed by three small intakes located in three different valleys respectively at 1,388 m.a.s.l., 1,344 m.a.s.l. and 1,285 m.a.s.l.. The intake structures are of the bottom (Tyrolean) type, particularly suitable to the site, thanks to the practically maintenance–free operation and because of the difficulty in reaching the intakes during winter. In the vicinity of the third intake, the nearest to the forebay a photovoltaic panel to supply energy to receive and transmit signals and to drive the valve at the forebay is located.

1.3. CHANNELS

The three intakes are connected by HDPE underground pipes, open flow working, 200/250/350 mm diameter, for an overall length of about 2.400 m. This material was chosen owing to its easy handling even by small tractors and trucks, the only vehicles suitable to operate in the narrow tracks on site. The installation of the pipes, including, excavations, welding and re-interment, lasted 8 months.

1.4. FOREBAY

A forebay is located at the end of the last canal. It is completely interred. The overall maximum water volume stored in the forebay is 180 m^3. The forebay is entirely realised in reinforced concrete. The only not interred side is coated with local stone. At the inlet of the forebay an electrically driven on-off butterfly valve is installed. The valve closes automatically when the water in the forebay starts flowing over the crest spillway of the forebay. At the forebay a valve room is located. It contains a manually driven gate valve to be closed in case of penstock maintenance, the emergency butterfly valve, automatically closing in case of the velocity in the penstock should exceed a pre-fixed value, an emergency generator equipped with a diesel engine to supply energy to drive the on-off valve and to channels monitoring (signals receiving and transmitting).

1.5. PENSTOCK

From the forebay starts the steel penstock, 400 mm diameter and 2600 long. The thickness varies from 6,4 to 11,1 mm. All welding was tested by ultrasonic devices; in the high pressure zone the welding was tested with X-rays. The most part of the penstock, about 2,250 m were interred for environmental reasons, despite of the steepness of the slopes, with remarkable installation problems. To make the penstock practically free from maintenance, it is without expansion joints, both in the interred and the outdoor zones. The penstock installation required about 10 months and it was carried out for more than 1,260 m by a “blondin” with three planimetrical curves, a rather unusual fact for this kind of system. The hydraulic test of the penstock (98 bar against the 80 of normal operation pressure) was more and more delayed because of the two sabotages carried out by unknown, but surely local authors.

1.6. POWERHOUSE

The powerhouse is located in the vicinity of the small village named Maroggia. It is very small, about 110 m^2 and it is composed of a single room where the generating set, the control panels and switchboard are located. At the rear of the powerhouse there is the switchyard from which starts the 15 kV 500 m long transmission line connecting the plant to the national grid.

1.7. ELECTRO-MECHANICAL EQUIPMENT

At the powerhouse a 2 jets - 800 mm runner diameter - 41 mm nozzles diameter - 1,500 rpm Pelton turbine (De Pretto Escher Wyss) directly coupled to a 6 kV-1800 kVA synchronous generator (ACEO-Alstom group) is installed. De Pretto-Escher Wyss supplied also the automation and control system of the generating set. It allows the unit to synchronise with the national grid and to regulate power at pleasure. The unit control is subject to the overall plant control system which carries out mainly the following functions: forebay water level regulation, management of hydraulic and electric alarms at the intake, penstock and powerhouse, tele-control and tele-transmission (by optical fibres running along the penstock) between forebay and powerhouse and between powerhouse and remote control centre, events protocol and plant measures recording.

2. MULTIPLE USE OF WATER AND GUARANTEES ON OPERATION REQUESTED BY RELEVANT AUTHORITIES

2.1. WOODLAND AREA FIRE CONTROL

The realisation of the plant gave relevant authorities the opportunity, thanks to the construction of a small road to feed Val Laresa intake yard, to improve the woodland area fire control by means of a small artificial water basin (100 m^3) near the intake works: a part of the diverted water is stored in the basin and it is used to fill choppers tanks in case of woodland fire events. It must be pointed out that the basin could have never been realised if Maroggia plant had't been, because of the high costs of the road facility necessary to the basin construction, which was completely in charge of Boselli. On the other hand an important multi-purpose use of water resource has been achieved with a consequent higher acceptability of the plant by relevant authorities.

2.2. RESERVED FLOW

Downstream of the three intakes a 20 l/s reserved flow - more than 4 l/s/km^2 - significantly higher than that fixed by the actual test law at 3 l/s/km^2 - must be released. The relevant authorities had already carried out a first measuring campaign - by a rudimentary volumetric method whose accuracy is doubtful - to control the effective release. A preliminary estimation was made by the salt wave method, particularly suitable to small torrents as Maroggia ones - to calibrate the orifices by which the reserved flow was released.

2.3. CHANNELS MONITORING

Relevant authorities required a continuous monitoring of the flow in open channel pipes to avoid leakage and prevent landslides. It has been obtained by six ultrasonic probes to measure flow rate: in case of important difference in measured velocities, the butterfly valve at the inlet of each pipe shuts down and interrupt the flow. This monitoring system, in the present first phase of operation, shows problems, especially at low flow rates at which the system is unstable and very sensitive to trash (levees, small wooden parts) conveyed by water. On the other hand, the investment cost of the monitoring system is relevant, about 2 % of the total cost, and the operation costs are high too, due to the maintenance required in an unaccessible zone.

3. DESCRIPTION OF THE EFFICIENCY MEASUREMENT SYSTEM

3.1. STANDARD REFERENCES

At the moment international standards regarding the field acceptance tests for small hydro units don’t exist. IEC 41 and 193 may be consulted, but it must not be overlooked that these codes were drawn up for large machines and that their requirements have to be adapted to the circumstances and operation climate of smaller installations. With regard to this aspect the Italian National Standard Body (UNI) in May 1993 issued a specific code (UNI 10242 – Small hydraulic turbines – Field acceptance tests) which we referred to in the execution of the tests. It is a simplified version of the IEC 41, very useful because the standard requirements are rather easily met even in small plants.

3.2. CONTRACTUAL REFERENCES

The contract signed between De Pretto-Escher Wyss and Boselli stated that the generating set (turbine+generator) must have an overall efficiency defined as follows:

η_{tot}=**46**η_1(Q=0.2 m^3/s;H=784 m)**+37**η_2(Q=0.15 m^3/s;H=798 m)**+17**η_3(Q=0.065 m^3/s; H =813 m)

The manufacturer guaranteed an average efficiency as above defined equal to 86,2 %. To keep into account the uncertainty in the measures, in the contract it was stated that the equipment would comply with the declared efficiency if during the field acceptance tests the average efficiency was superior to the declared one minus 3 %; this value derives from the combination of the worst uncertainties in the single measures: actually, UNI 10242, on a statistical basis, states the uncertainty on efficiency at 1,8 %. As we were dealing with contractual clauses, we preferred to be conservative. Furthermore, the choice of the uncertainty results from a costs-benefits analysis showing that the contractual benefits in reaching very high precision in the tests are not compensated by the costs of the instruments and relevant installation.

3.3. DISCHARGE MEASUREMENT

The volumetric gauging method was utilised. The conditions stated in IEC 41 were substantially met, thanks to the presence of an artificial basin, the forebay, with vertical walls, well-defined from the geometrical point of view, without any disturbances due to wind - the forebay is completely closed – waves – the water surface is large enough to avoid the formations of significant waves during the emptying of the basin. The water level measurement during tests - and during normal operation too - was carried out by means of an immersible pressure transducer system which guarantees an error inferior to 0.5 % over the range of the test. The variation in water level during test varied from 139 cm (83.40 m^3 volume) in the maximum discharge test to 60 cm (36.00 m^3) in the minimum discharge test. The duration of the test was measured by a high precision (1/1000”) chronograph. During the test the variation in water level was measured every 10 seconds, as well as the other entities to be measured. Such a recording showed that instantaneous discharge was practically equal to average discharge during the measure.

3.4. SPECIFIC ENERGY (HEAD) MEASUREMENT

The head was measured in two different ways: by a spring pressure gauge and with a pressure transducer. Both devices were calibrated before and after the tests and they assured an error inferior to 0,2 % within the measuring range. The manometers were installed on a 200 mm pipe just upstream of the bifurcation which feeds each jet: as the diameter is very small and the head very high, there’s no need for a multiple manometer installation at the measuring section. Moreover, as the kinetic energy at the section is very small compared with the pressure energy and inferior to the pressure device, it could be neglected. In this case we took it into account, although the final result wasn’t substantially affected by the presence of the kinetic energy term. To correctly calculate the specific energy the right value for water density and gravity acceleration must be considered. The gravity acceleration is a function of latitude and altitude, so we corrected the usual technical value, 9,81 m/s^2, and we obtained 9,808: the utilisation of the usual value should imply an error of 0,02 %, practically negligible.

3.5. ELECTRICAL POWER MEASUREMENT

The Aron connection (a two-wattmeter method, valid under balanced and unbalanced conditions) was adopted for the measurement of the electrical power. During the run, the power was measured every ten seconds, as any other quantity. The electrical power readings showed to be very stable. The wattmeter class was 0,1: this ensured a high accuracy of the readings. On the other side, greater accuracy of the wattmeters was unnecessary, because on board voltage and current transformers showing 0,5 class were used.

4. TESTS EXECUTION

4.1. TEST CONDITIONS

The nozzles opening corresponding to each conditions of tests were fixed by De Pretto-Escher Wyss. At conditions nr. 1 and 2 the nozzles opening was the same for each nozzle (91,3 % and 57,3 %); at condition nr. 3 the tests were carried out with the lower nozzle only opened at 47 %. During each test the on-off valve at the inlet of the forebay was closed in order to avoid any disturbance due to the inflow.

4.2. TEST DURATION

Three tests were carried out at the maximum discharge condition – two at PF ≈ 1,00 and one at PF ≈ 0,8 – and two tests for each one of the other conditions – Q = 150 l/s and 65 l/s. The tests duration varied from 398 s – 77,40 m^3 of water discharged at 194,47 l/s - to 601 s – 36,00 m^3 of water discharged at 59,90 l/s. The effective duration of each test depended essentially by the time required to filling the forebay; as the natural inflow was very low because the tests were carried out in winter (about 40 l/s) the overall duration of each test was about one hour. Nevertheless, all the tests were executed in one day only, beginning at 9.00 a.m. and ending at 18.30 – all the preliminary and final instrument installation and removing included.

4.3. TEST RESULTS

The results of the tests are summed up in the following tables:

Test	Nozzle 1	Nozzle 2	Duration	Volume	Flow rate	Power	PF	Head	η
1	91,3	91,3	398	77,40	194,47	1.281	0,977	783,03	85,74
2	91,3	91,3	430	83,40	193,95	1.284	0,990	783,03	86,19
3	91,3	91,3	429	83,40	194,41	1.270	0,786	783,03	85,03

Average efficiency: **η_1 = 85,65 %**

Test	Nozzle 1	Nozzle 2	Duration	Volume	Flow rate	Power	PF	Head	η
1	57,3	57,3	590	83,40	141,36	946	0,780	797,31	85,75
2	57,3	57,3	588	82,80	140,82	944	0,782	797,31	86,54

Average efficiency: **η_2 = 85,65 %**

Test	Nozzle 1	Nozzle 2	Duration	Volume	Flow rate	Power	PF	Head	η
1	0	47	601	36,00	59,90	399	0,778	810,56	83,11
2	0	47	593	36,00	60,71	401	0,776	810,56	83,73

Average efficiency: **η_3 = 83,42 %**

Average efficiency of the generating set: $\eta_{tot} = 46\eta_1 + 37\eta_2 + 17\eta_3$ = 85,27 %

Even if the average efficiency was inferior to the contractual one (86,2 %), it complies with the contract statement.

4.4. TEST REPEATABILITY

Thanks to the simplicity of the instruments required and the quickness in their installation and removing, the tests will be easily repeated at each time in the plant life, to check eventual worsening in the generating set performance. The easy repeatability of the tests is due to the fact that right since the conception of the plant provision has been made for the measurement of the quantities involved in the tests.

4.5. Test cost

As we said, the plant was already arranged for field acceptance tests execution, so that no further expense was necessary to adapt it to the tests conditions. So the test cost is essentially due to the personnel involved in the measurements. In the specific case of Maroggia, where the measuring devices weren't equipped with data recorders, four persons were necessary to tests execution. If the tests were carried out with measuring devices equipped with data recorder, two persons only would be enough. So the test execution costs about 1.000 euros.

4.6. Major cost to adapt the plant to test execution

In the specific case of Maroggia, this estimate is not very easy because the field tests were envisaged and since the conception of the plant we have made provision for the measurement of head and flow in order to achieve an integrated design where the plant parts "devoted" to the tests have a role in the normal operation of the plant.
As a matter of fact, it has been only necessary to insert pressure taps on the final part of the penstock - at a negligible cost, and to provide the forebay with a pressure transducer to measure water level which anyway was necessary for the plant operation.

5. CONCLUSIONS AND REMARKS

The guarantee of the best exploitation of water resource for hydroelectric purposes is one of the conditions to make small hydro plants more easily accepted in the renewable scenario. The best exploitation is achieved, among other things, by installing high efficiency hydro units. In this frame it becomes important to carry out field acceptance tests to determine the performances of the generating sets even for small hydro plants, where they are very often neglected. The tests carried out at Maroggia multi-purpose plant showed that it's possible to check performances at low cost with remarkable simplification in measuring procedures in comparison with the international standards, without loosing reliability as long as the conception of the plant provides for the measurements in an integrated design approach.
In our thought, a procedure to remove a part of the hindrances met in implementing new SHPs could be divided as follows:

- To install high efficiency units to demonstrate to relevant authorities the best exploitation of the water resource and declare the average value of the efficiency (this fact could even represent a incentive for manufacturers to improve their products)
- To carry out periodic efficiency tests on the plants - at the presence of the relevant authorities - in order to check the declared efficiency.

As the above mentioned procedure generally implies an increase in the investment and operation costs, it could be implemented provided that relevant authorities take them into account - e.g. by means of financial incentives to cover the major investment in high efficiency units or recognising an higher value to the energy produced, especially if the plant is connected to national grid.