Turbine acceptance tests at Frieira HPP, Miño River, Spain with Acoustic Scintillation Flow Meter and Current Meters

Dario González Salgado and Jordi Vich Llobet, Gas Natural Fenosa, Spain

Dr. Fabio Muciaccia and Dr. Gianalberto Grego, W.E.S.T., Italy

Murray Clarke and David Lemon, ASL AQFlow Inc., Canada

Abstract

In October 2007, Gas Natural Fenosa (formerly called Union Fenosa Generación) successfully made flow measurements with the Acoustic Scintillation Flow Meter (ASFM) to establish the operational efficiency of existing turbines at their Velle, Frieira and Castrelo hydroelectric plants on the Miño River in north-western Spain. Subsequently, company personnel stipulated in their contract for replacement runners at these three plants that the ASFM would be used in the field acceptance tests in conjunction with flow measurements by the current meter method. The first of these tests took place on Unit 1 at the Frieira plant in June 2011. The Frieira plant has two Kaplan units, with nominal flow of 374 m^3/s and the net head of 24.5 m.

The results of the two methods were all within 1% and are discussed in the paper in detail, along with the procedures for the installation of the instruments and data collection.

Introduction – Acoustic Scintillation

As there are no slots which could be made available for the measurement, the ASFM had to be mounted on the walls of the intake bays downstream of the gate slot (Fig. 1). The following factors were considered in the design of the mounting system:

- minimum interference with the flow from protrusions into the flow area,
- accurate alignment of, and distance between, the transmitting and receiving transducers,
- ease of installation.

Innovative two-part portable frames were utilized: the fixed base plates were bolted to the walls in each intake bay ahead of the measurement, during a unit outage, while the intake was dewatered. The two sets of portable frames holding the transducers were fully instrumented in the yard, also in the dry. These were then attached to the base plates in the intake bays under water by divers.

Each portable frame contained 15 holes for transducers. The transducers were installed on the frame and the transducer array cables were connected to the receiver and transmitter canisters that were placed above the frames. A receiver surface cable was connected to the receiver canister, a control surface cable to the receiver canister, a transmitter surface cable to the transmitter canister, and interconnect (ICC) cable connected both canisters.

Fig. 2 shows the ASFM frames and Gas Natural Fenosa personnel installing the components of the ASFM on a frame. The fully instrumented frames were lowered into the slot using an overhead crane and bolted onto the base plates. The Group A and B canisters were bolted directly to the intake wall.

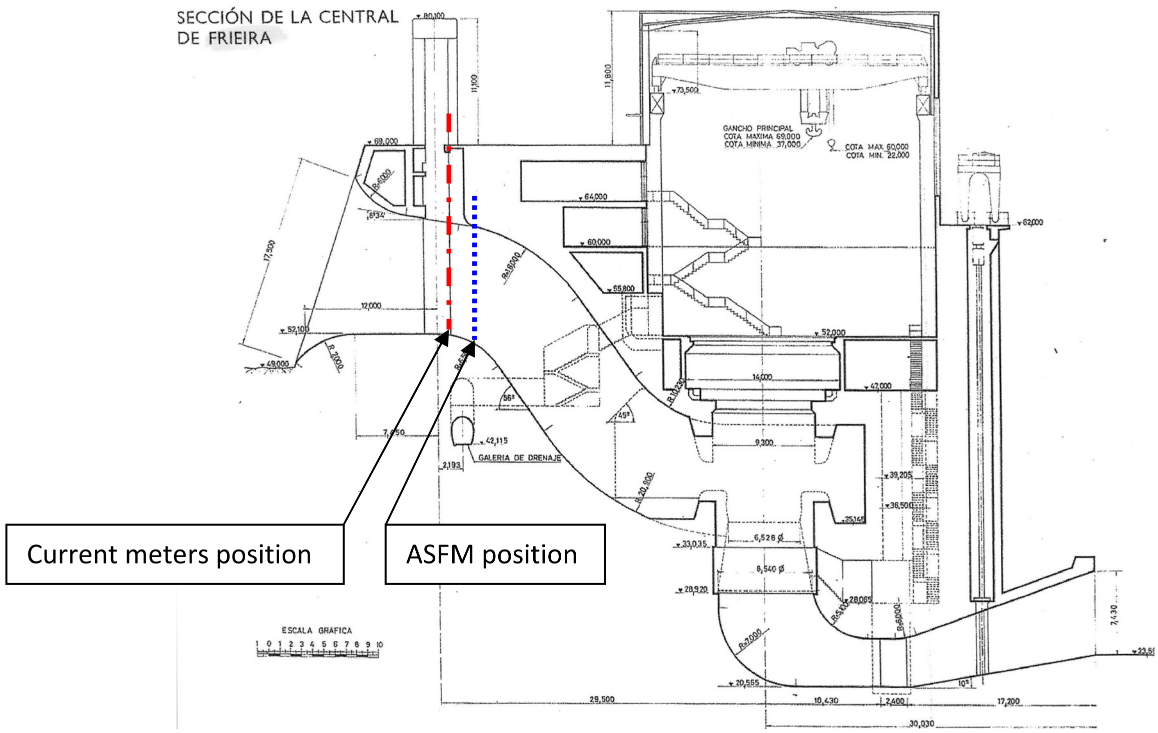

Fig. 1 – Frieira HPP

Fig. 2 – ASFM frames (2007 measurements)

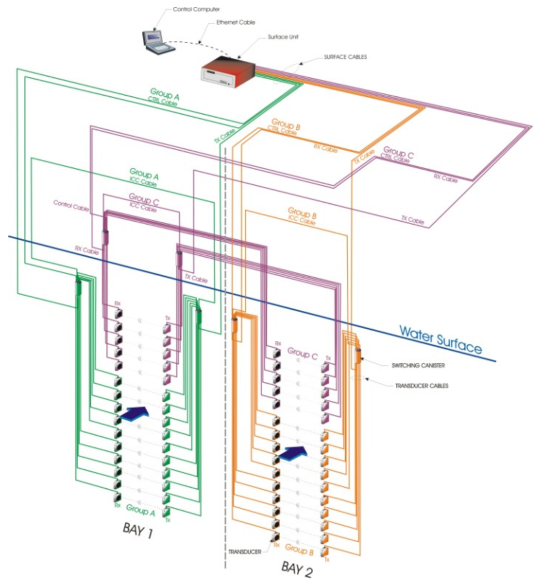

Fig. 3 – ASFM components

Fig. 3 shows a schematic diagram of the components of the 15-path per bay ASFM as installed. It consists of five major components: transmitting (Tx) and receiving (Rx) transducers and underwater cabling, switching canisters, surface connection cables, a data acquisition surface unit, and a PC computer with the user interface for controlling and operating the ASFM.

The plant has two Kaplan units, with nominal flow of 374 m^3/s and the net head of 24.5 m. The first test took place on Unit 1 in June 2011.

Introduction - Current Meters

The flow rate was measured with sixty current meters (CM) mounted on two frames just downstream of the gate slot (Fig. 1), one for each intake bay. Each frame had two rods of ovoid profile, 35x105 mm, at a distance of 800 mm, to which the CM were attached (Fig. 4).

Fig. 4 – CM frame

Fig. 5 – Lifting system

The lifting of the frames was performed with the use of three winches, positioned one at the center of the frame, and two at each side as shown in Fig. 5.

Two lateral guides, made with 100 x 100mm L-profiles and spaced 520 mm, were installed on the walls to allow vertical lifting of the frame through the full height of the intake and the measurement of the entire flow velocity field (Fig. 6).

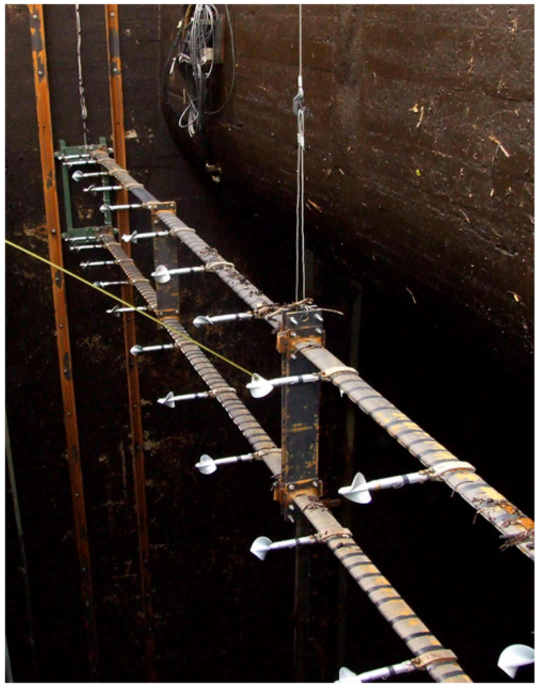

Fig. 6 – Lateral guides

Test Program – Acoustic Scintillation

The magnitude and inclination of the flow velocity in the intake was computed using 33 second measurements at each level. Six to seven individual repeat runs were made at each condition. Roughly 40 minutes was necessary to obtain individual discharges for each condition.

The basis of the ASFM velocity measurement is the time-lagged correlation of the time series of acoustic amplitude fluctuations recorded over two spatially separated paths. Six to seven sequential time series were collected at each level during the normal course of these tests; each sequence was treated as described in Ref. 1 and 2.

The horizontal velocities from the individual repeat runs at each level were averaged and the discharge was computed by integrating the average velocity profile using a quadratic interpolation scheme.

Sample horizontal velocity plots are shown in Fig. 7 (the averaged velocities of the repeat runs are in red, the individual velocities in grey).

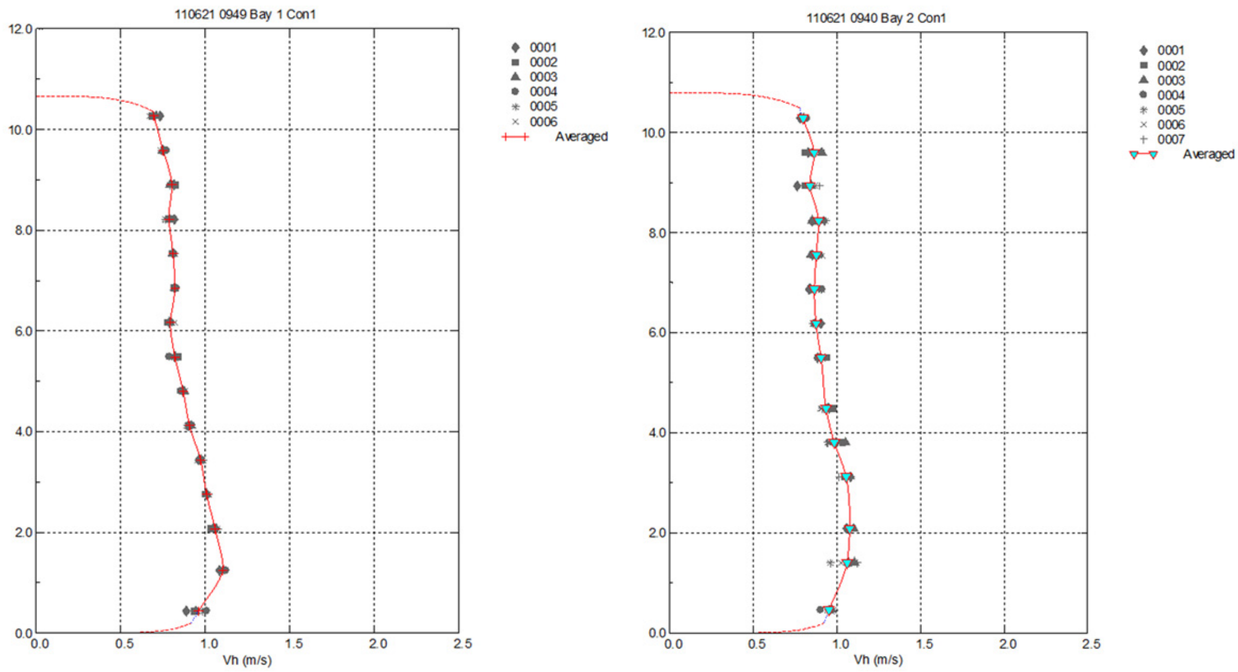

Fig. 7 – ASFM sample horizontal velocity plots

The roof and floor of the intake and the sides of the frame holding the ASFM transducers define a plane surface, *S*, through which the flow must pass. The discharge is therefore given by the flux through *S*:

$$Q = \oint_{S} V \cdot n \quad da$$

where V is the velocity vector (a function of position in the plane) and n is the unit vector normal to the plane. The ASFM measures the lateral average of the component of velocity normal to the propagation path; if z′ is the vertical coordinate, then the discharge, Q, in terms of the laterally-averaged velocity, v, is:

$$Q = \int_{0}^{H} v(\mathrm{z}') \cos[\theta(z')] \cdot L \quad dz'$$

where $v(z')$ is the magnitude of the laterally-averaged velocity at elevation z', $\theta(z')$ is the corresponding inclination angle, $L(\mathrm{z}')$ is the width between the transducer faces, and H is the height of the intake roof above the floor. The lateral averaging performed by the ASFM is continuous, while the sampling in the vertical was at 15 discrete points. Calculating Q then requires estimation of the integral when the integrand is known at a finite number of points. The integral was evaluated numerically using Romberg integration, with a quadratic interpolation in the integrand between the measured points. The accuracy of the integration depends on the sampling levels being placed properly to resolve the variation of the horizontal velocity with elevation. The measured points do not extend all the way to the intake roof and floor; as a result, complete evaluation of the integral requires an evaluation of the flow in the zones next to those boundaries.

It was necessary to impose a form on the normal component of the velocity to allow the evaluation of the integral to be completed between the measured points at the top and bottom extremes and the corresponding boundaries at the floor and roof. A closed boundary was imposed at each of the boundaries. At the floor, a curve of the form:

$$\left[\frac{z}{T}\right]^{\frac{1}{X}}$$

was fitted for the measured profiles in between the floor ($z = 0$) and the boundary thickness $T =$ 0.2 m using a curve with the parameter $X = 7$. A linear extrapolation was used from the first measurement point (0.444m in Bay 1, 0.417m in Bay 2) to T.
At the roof, a curve of the form:

$$\left[\frac{Zr - z}{T}\right]^{\frac{1}{X}}$$

was fitted for the measured profiles in between the top measurement point (z = 10.131m in Bay 1, 10.237m in Bay 2) and the roof (Z_r = 10.605m in Bay 1, 10.737m in Bay 2) using $X = 4$ and a thickness T of 0.3m. Both X values of 7 and 4 are within the values specified in Annex E of ISO 3354:1988 (ISO 1988).

Preliminary discharge results were supplied to Gas Natural Fenosa for comparison to the current meter method as the tests were proceeding. The final values, provided after verification and checking, show only minor differences resulting from changes to the dimensional measurements of the intake, as supplied by Gas Natural Fenosa after the measurement.

Test program – Current Meters

During each of the eleven tests the frame with the current meters was moved vertically into eight positions, thus exploring the measurement section in sixteen different horizontal levels. Therefore, the flow of each intake bay was calculated from the flow velocity measurement at 240 points (16 levels with 15 points each), with an acquisition time for each local velocity of 180 seconds.

The determination of the flow rate has been achieved, as required by IEC 60041 and ISO 3354 codes, by integrating the flow field in the horizontal planes first, and then vertically according to the expression:

$$Q = \int_0^H \left(\int_0^L V \, dl \right) dh$$

The flow rate was calculated by using the method of cubic interpolation between the measured points (J. Coffin and the method of Spielbauer, Ref. 3) or by the method of trapezoids. The integrations were carried out directly by computer via numerical equations, as required by the codes, and extrapolation to the vertical side walls as follows:

$$V_x = V_a \left(\frac{X}{a}\right)^{1/n}$$

where $4 < n < 10$. The value of n was calculated from the average of the values obtained by extrapolating the trend in proximity to the wall derived from the flow velocity detected by the current meters closest to the wall. All sixty current meters worked properly during all tests: no foreign bodies in the water impacted the behavior of the propellers. The thruster control, carried out at the end of the tests, confirmed their smooth operation.
Figures 8 and 9 show examples of the contours of the velocities measured in the two intake bays.

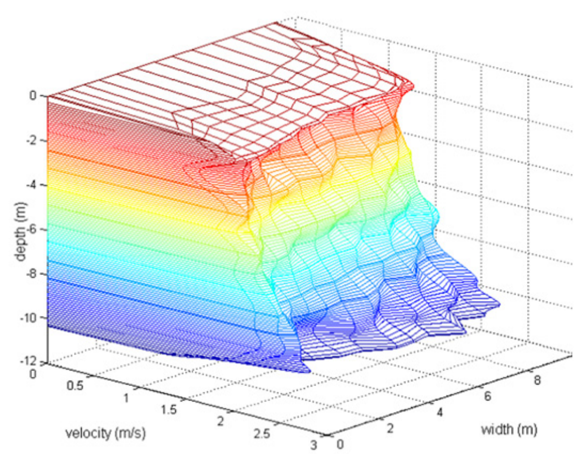

Fig. 8 – CM velocity contours Bay 1

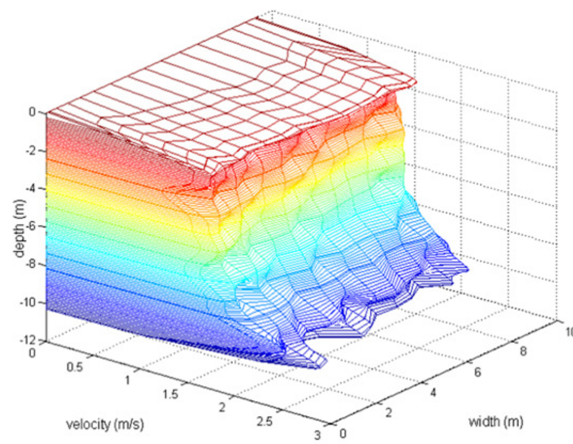

Fig. 9 – CM velocity contours Bay 2

Results Comparison

The average standard deviation of the individual ASFM repeat runs made at each condition was 0.52% in Bay 1 and 0.78% in Bay 2 (Table 1).

Table 1:

Scintillation	
Bay 1_stdev	Bay 2_stdev
(%)	(%)
0.57	0.90
0.34	0.77
0.56	0.65
0.44	0.61
0.57	0.88
0.67	0.80
0.45	0.68
0.57	0.84
0.68	1.02
0.45	0.73
0.40	0.71

As the Table 2 shows, the results of the two methods were all within 1%.

Table 2:

	Current Meters		**Scintillation**		**Bay 1**	**Bay 2**	**Current Meters**	**Scintillation**	**Total flow**
	Flow – Bay 1	**Flow – Bay 2**	**Flow – Bay 1**	**Flow - Bay 2**	**Delta**	**Delta**	**Total flow**	**Total flow**	**Delta**
Condition	**(m^3/s)**	**(m^3/s)**	**(m^3/s)**	**(m^3/s)**	**(%)**	**(%)**	**(m^3/s)**	**(m^3/s)**	**%**
1	86.897	92.478	86.6	92.5	-0.31	0.05	179.375	179.153	-0.15
2	110.487	117.575	110.8	117.6	0.26	-0.01	228.061	228.339	0.15
3	128.827	138.128	129.9	138.4	0.84	0.20	266.955	268.305	0.50
4	149.100	157.013	147.7	158.8	-0.95	1.16	306.113	306.516	0.13
5	166.530	177.109	165.6	177.2	-0.54	0.06	343.639	342.842	-0.24
6	110.044	116.461	109.9	116.8	-0.09	0.25	226.505	226.694	0.09
7	130.202	137.726	131.3	138.6	0.87	0.61	267.928	269.911	0.74
8	136.210	143.524	137.8	144.3	1.15	0.53	279.734	282.067	0.85
9	154.684	162.283	153.8	163.0	-0.59	0.47	316.967	316.809	-0.05
10	107.773	114.137	108.3	113.8	0.45	-0.33	221.909	222.025	0.09
11	195.968	203.331	195.3	205.4	-0.34	1.00	399.299	400.666	0.35

References

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3. M. Spielbauer, W.F.O. Müller, Numerisches Integrationsverfahren zur Auswertung von Flügelmessungen, Die Wasserwirtschaft 11, (1969) 313-320

The Authors

Darío González, Eng., graduated in Industrial Engineering, electrical speciality from Escola Superior de Enxeñeiros Industriais de la Universidad de Vigo (Spain) in 2004. He is now performing efficiency measurements and is responsible for Optimization and Technical Control of Hydraulic Power Plants with Gas Natural Fenosa. He was in charge of electrical commissioning of Norte Combined Cycle Plant in Durango (Mexico).

Jordi Vich, Eng., graduated in Industrial Engineering, Thermoenergetical specialty from Escola Superior d'Enginyeria Industrial de Barcelona, Universitat Politècnica de Catalunya, Barcelona (Spain) in 2000. He is now Head of Maintenance & Local Operation of Hydraulic Power Plants with Gas Natural Fenosa. He was in charge of the studies and efficiency measurements for a project of Rehabilitation by runner replacement of 21 hydraulic units.

Fabio Muciaccia, Dr.Eng., graduated in Mechanical Engineering, at the Politecnico di Milano, and has more than 30 years experience in testing with the Hydroart and Voith Italy . He is now President of WEST (Italy). He is vice-president of IGHEM and Secretary of IEC TC4 Italian Committee; he is active in international committees within IEC. He has several international publications covering hydraulic aspects of power plants and is expert in thermodynamic and current meter measurements.

Gianalberto Grego, Dr.Eng., graduated in Electrotechnical Engineering, at the University of Padova, and has more than 30 years experience in testing, being for many years chief of the Hydro Development in CRIS and in ENEL. He is now Chief of Hydraulic Services in WEST (Italy). He has been vice-president of IGHEM and active in international committees within IEC. He has several international publications covering hydraulic aspects of power plants and is expert in acoustic transit time and current meter measurements.

Murray Clarke, B.A.Sc. (Electrical Engineering), graduated from the University of British Columbia, Vancouver, in 1989. He has been an electronics designer at ASL AQFlow since 1991, responsible for design and testing of electronics for acoustic and other instruments, including the acoustic scintillation flow meter.

David Lemon, M.Sc., graduated in Physics (Oceanography) from the University of British Columbia, Vancouver, in 1975. He is President of ASL AQFlow Inc., Victoria, BC, with responsibility for internal research and development. He has been responsible for the development of the acoustic scintillation method for discharge measurement in hydroelectric plants.