Deployment Methods for
The Acoustic Scintillation Flow Meter

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Abstract

The acoustic scintillation flow meter (ASFM), also sometimes called the cross-correlation flow measurement technique, has been used to make turbine discharge measurements in over 30 different low-head intakes in the past 10 years.

Design considerations relevant to field deployment include placement of transducers on installation frames, minimization of flow interference and particularly vibration, as vibration can interfere with acoustic signals and reduce measurement accuracy. Considerations for steel frame design and deployment, including crane handling of the frames, are also covered.

The use of the ASFM frames at two different sites is described in detail. The first example covers measurements at Unit 4 at Lower Granite Dam (810 MW plant capacity) on the Snake River in Washington State. This 135 MW Kaplan unit with a 3-bay intake is operated by the Walla Walla District of the US Army Corps of Engineers. The second example describes measurements at a 74-unit plant owned by Edison Sault Electric Company in Sault St Marie, Michigan. Units have a capacity of about 400 to 600 kW each, and measurements were carried out at all most every unit over a three-week period.

Introduction

Acoustic scintillation was first applied as a method for measuring flow in an intake of a low-head hydroelectric plant in 1992, using instruments adapted from oceanographic use. The first version of an instrument designed specifically for use in hydroelectric intakes (the Acoustic Scintillation Flow Meter, or ASFM) was used at McNary Dam on the Columbia River in 1998.

The basic principles of acoustic scintillation (or cross-correlation, as it is also known, particularly in Europe) flow measurement technique are described in detail in Lemon, Billenness and Lampa (2002), Farmer and Clifford (1986) and Clifford and Farmer (1983). Briefly, the technique utilizes the natural turbulence embedded in the flow, as shown in Figure 1. In its simplest form, two transmitters are placed on one side of the intake, two receivers on the other. The signal amplitude at the receivers varies randomly as the turbulence along the propagation paths changes with time and the flow. If the two paths are sufficiently close (Δx), the turbulence remains embedded in the flow, and the pattern of these amplitude variations at the downstream receiver will be nearly identical to that at the upstream receiver, except for a time delay, Δt. This time delay corresponds to the position of the peak in the cross-correlation function calculated for Signal 1 and Signal 2. The mean velocity perpendicular to the acoustic paths is then $\Delta x/\Delta t$, and because three transmitters and three receivers are used at each measurement level, the average inclination of the velocity is also obtained. The total flow is then calculated by integrating the average horizontal component of the velocity at several pre-selected levels over the total cross-sectional area of the intake.

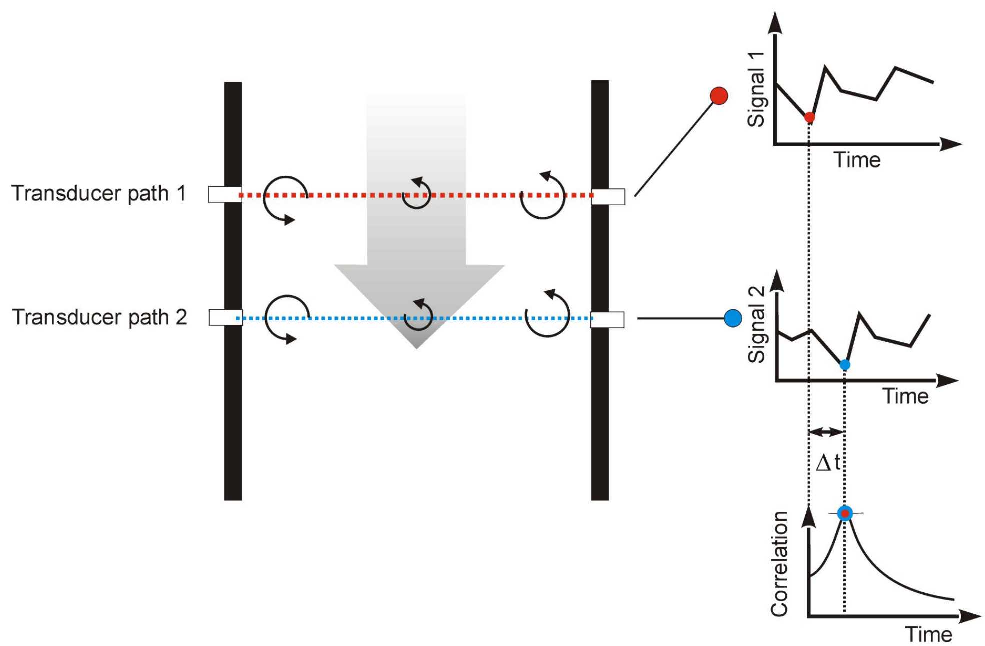

Figure 1: Schematic representation of the acoustic scintillation principle

Because the measurement is carried out perpendicular to the flow, long sections of uniform profile conduit are not required. This makes the ASFM suitable for flow measurement in short, rapidly converging intakes of low-head hydroelectric plants. Since 1998, the ASFM has provided accurate and cost-effective measurements at more than 30 such plants.

Another defining feature of the ASFM is the placement of instruments on frames, which are then inserted into existing stop-log or gate slots (Fig 2). The instruments are thus ‘hidden’ in the slots, do not interfere with the flow and are protected from debris impact. Intake dewatering is not required for instrument installation or removal, as fully instrumented frames are moved into and out of intakes as required.

The discharge measurement accuracy depends on the number and placement of the acoustic array paths. There are two basic approaches to path placement: a sufficient number of paths mounted at fixed elevations spanning the full height of the intake (e.g. Fig 2), or only one or two paths mounted on a suitable frame which is moved though a series of positions to sample the full intake height. The two examples included in this paper describe the fixed frame application. The moving frame application is covered in Proulx, Cloutier, Bouhadji and Lemon (2004).

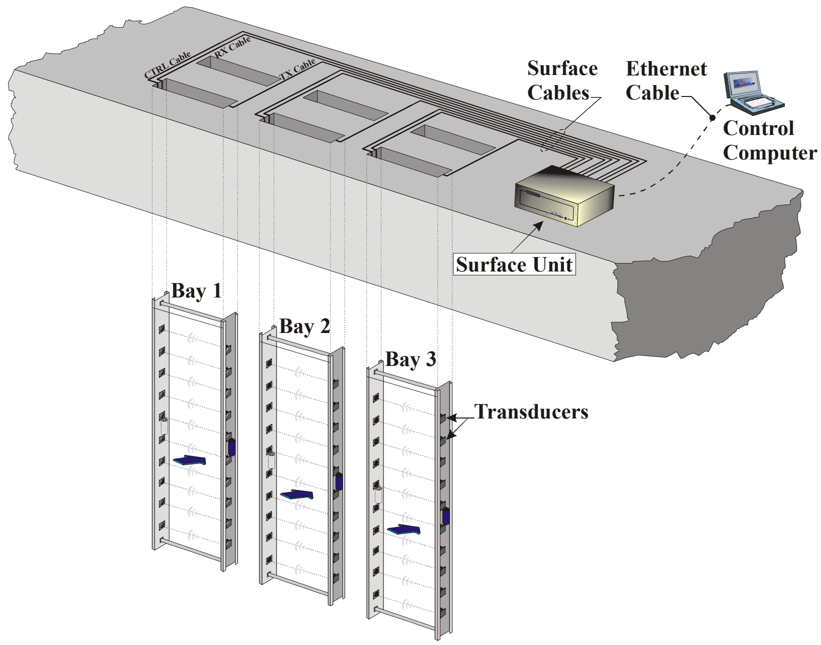

Figure 2: Typical installation arrangement for an ASFM

Fixed Frame Design Considerations

a. General

The frame needs to fit securely and accurately in the slot. Correct dimensions and surface conditions of the slot to be used for frame installation need to be verified – this is especially important for older plants. Operators may have anecdotal information about condition of the slot and its last use. A pre-measurement fit of the frame in the slot is critical to ensure that no time is wasted during the measurements. Slots can accumulate debris which requires removal. If possible, the sides of the frame should fill the entire slot, and there should be a minimum of cross-members in the flow. Such design maximizes the non-intrusive nature of the ASFM. If the frame is offset into the flow, then it will shed vortices and create frame vibration which may be picked up by the transducer arrays introducing measurement error.

The mounting frame needs to be structurally strong enough to support hydraulic forces along with lifting beam loads and forces. In the event that it jams in the slot, the frame needs to withstand the extreme lifting forces imposed by the crane. Designers need to consider the assembly, installation and removal procedures, emergency frame restraint, retrieval devices and procedures.

b. Site Specific Conditions

Site access and availability of suitable lifting equipment for installation and removal of the frame should be considered. The frame will need to be designed to fit site specific conditions due to variances in slot dimensions, overall intake configuration, etc. Consideration should be given to where the frames will be instrumented and how they will be moved following instrumentation. The frames must be fully assembled prior to instrumentation. Therefore space requirements may dictate the methods used for handling and the frame design must accommodate this logistical requirement. At Lower Granite, the frames were assembled on site in a horizontal position, blocked up in a level position and instrumented. Once instrumented, a mobile crane was used to stand the frames up and install them in a dogged position in a gate slot. Once the frames were dogged into a slot, the gantry crane was used to pick and move them to the test unit. The gantry crane was also used to deploy them in the final position. The frames are designed to sit on the floor of the intake. The frame picking ears need to match the design of the existing lifting beam on the intake gantry crane or a separate lifting beam must be provided. In addition, methods for movement of the frame by mobile crane need to be determined.

c. Flexibility

Providing frame components that can be bolted together can be advantageous, as it will permit breaking down the frame for storage or transportation to another similar site. It may be appropriate to include some adjustable features in the design such that components maybe fine-tuned in the field to fit the slot. Shims (added or taken away) can be used to adjust the fit of the frame within the slot width. For example: The Lower Granite, Little Goose and Lower Monumental turbine intake configurations are identical with similar approach flow conditions, allowing for a frame design which can be used for all three plants. Each plant has 6 units for a total of 18 Kaplan units. Three frames are required to be deployed for discharge measurement of a single turbine unit. These frames were designed to be bolted together so they could easily be disassembled and transported by truck from one project to another. The frames when assembled are approximately 24 by 52 feet. Each frame weighs approximately 16 tons.

d. Vibration Considerations

The mounting frame should provide a stable, vibration-free transducer mount that has little or no effect on the flow being measured. As the measurement frame is usually positioned downstream of the trash rack, appropriate care needs to be given to the turbine safety. The frame must be structurally sound and able to withstand the forces that are placed on it. In the event that actual flow conditions are difficult to predict it may be necessary to instrument the frame with strain gages and accelerometers. The flows can be incrementally increased to verify that the vibrations and stresses on the frame are acceptable before the ASFM instrumentation is added to the frame.

Vibrations in the transducer support structure in the range of 5 to 30 Hz cause a systematic error in the shape of the correlation curve and affect the computed velocity. The design of the mounting frame must therefore ensure that the frame does not vibrate significantly at frequencies between these two limits and that the amplitude of any vibration outside that range is small (<0.2”). Frame vibration can occur for two reasons. Vibration can be transmitted from the concrete to the steel frame. To avoid this kind of problem, shock-control vibration isolators can be used both at the bottom and on the sides where the frame contacts the concrete. If components of the frame (such as a cross-member) are mounted in the flow, turbulence and shedding of vortices will be created. If the frequency associated with these vortices is near the natural frequency of vibration of the cross member, the vibration may adversely impact the measurement accuracy. In extreme cases, the frame may even disintegrate causing damage to the turbine.

Using the definition of the Strouhal Number *S* from Avallone and Baumeister (1987):

$$S = F\frac{D}{V}$$

where F is the wake frequency (s^{-1}), D is the diameter of the cylinder (m) and V is the velocity of the flow (m/s), the wake frequency may be calculated for various conditions. An assumption was made with respect to the value of S for the appropriate Reynolds number and a cross-sectional shape of the member. The induced frequency (F) increases with increasing water velocity (V). Using the basic equation for the natural frequency F_{nat} of a mechanical component represented by

$$F_{nat} = \frac{1}{2\pi}\left(\frac{k}{M}\right)^{\frac{1}{2}}$$

where k is the stiffness of the structure and M is the mass (kg) of the system in motion, the natural frequency of the cross member may be computed. Our experience has shown that unless F_{nat} is more than $5F$, the vortices may excite the cross member.

At the Edison Sault Electric plant a 5” x 5” x ¼” square structural steel tubing was used successfully for a span of 15 ft and velocities of up to 2.5 ft/s. At several US Army Corps of Engineers plants on the Columbia and Snake Rivers a 12” diameter schedule 40 steel cross pipe has been used successfully for velocities of up to 8 ft/s and a span of 20 ft.

If any portion of the frame is placed in the flow, the measurement accuracy may be adversely affected. In the frame design, consideration needs to be given to the impact of such members. Computational Fluid Dynamics (CFD) modeling estimates may be applied to the regions of the flow that are difficult to measure.

e. Number and Placement of Paths and Transducers

Consideration should be given to the anticipated hydraulic conditions and the presence of upstream structural or natural features which could effect the flow distribution entering the intake. Any available velocity data from past field data collection efforts or physical hydraulic model studies should be utilized to help identify the best locations for transducers and path spacing. Additional transducer mounting locations can be provided on the frames with associated bolt-on covers so that path locations can be easily changed if desired.

f. Cabling Considerations

At each transducer location, a cable tie device should be placed within 6 inches on either side of the transducer. The ability to tie off the cable close to the transducer will prevent water flow from acting on the cable and damaging the connection of cable to transducer. Cable tie off locations should be provided at both the upstream and downstream edges of the frame at 2-3 ft intervals.

At the top of the frame, provision of a tie off for a rope should be considered. The rope will be used to carry the weight of the cables which will be routed from the top of the frame to the deck during deployment. The surface cables are taped to the rope.

Switching canister locations must be considered and be located on the frame within the available length of cable. Cable must be routed from one side of the frame to the other. Cable should be routed through the horizontal frame member so that it is protected from damage due to water flow or crane handling of the frame.

Field Deployment Methods

The ASFM assembly starts with the surface cables being attached to the frame, typically set up horizontally on pedestals and leveled to facilitate the installation of the ASFM components. The transducers are then placed into the holes in the frame with their faces flush with the sides of the frame, so that the full width of the intake is sampled, the transducers are protected from floating debris and no flow interference is created.

a. Operational Checks – Dry Conditions
The dimensional parameters that must be measured before the frames carrying the transducers are put into the intake slots are as follows:

- The elevation of the bottom edge of each transducer with respect to a reference level such as the bottom edge of the frame;
- The distance between each pair of transmitting and receiving transducers;
- The inclination of the bottom edge of each transducer with respect to horizontal when the support frame is vertical.

The reference used for the elevation measurements must be one which can be accurately related to the dimensions of the intake, so that an accurate discharge measure can be obtained. Elevation and path length measurements must be accurate to 0.5% or better if accuracy better than 1% is desired in the flow measurement. For typical intake dimensions, that requires an accuracy of 1 inch or better, which is usually possible with a steel tape measure.

Measuring the inclination of the transducers may be done with the support frame in the same position it would take in the intake. In most cases, placing it in the gate repair pit allows that to be done. Once the frame is hanging properly, then a digital level may be placed along the bottom edge of each transducer. If it is not convenient to use the repair pit, the transducer orientation measurements may be taken with the frame lying flat on the deck. The frame should be supported so that it is as nearly level as possible, and free from sag or twist, and then the deviation of the reference edges of the transducers from the perpendicular to the frame sides is measured. Note that it may be easier to adjust each transducer to 0 degrees (±0.2 degrees) before tightening it onto the frame.

These geometric parameters should be measured again after the frames have been deployed.

b. Operational Checks – Wet Conditions
After the ASFM frame had been installed into the gate slot, the surface cables should be connected to the surface units and the Ethernet cables to the control computer (Fig. 2) and the initial operational checks performed to check for satisfactory acoustic signal acquisition with no flow in the unit. No-flow conditions produce nearly constant signal amplitude levels, as the absence of flow means there is no turbulence present to produce fluctuations. The absence of fluctuations under these circumstances confirms proper operation of the instrument under no-flow conditions and serves as a zero check. The zero flow check serves as one test on the system, but the system should be also normally checked with flow through the unit.

The ASFM uses time-division multiplexing to separate and identify the signals arriving at the receiver. The transmitters do not send sound signals continuously, but in a set pattern. Reflected signals arriving over a route other than the direct path between the transmitter and receiver can interfere with the expected pulse pattern at the receiver and confuse the signal identification process. These reflections, called multipaths, can arise because the transducers have a beam 10° wide with weaker side-lobes. Normally, interference arises when signal paths are too close to surfaces, so that multipaths overlap the direct signal. The path lengths entered to the program are used by the ASFM to compute the precise arrival time for each transmission, and therefore reduce the confusion caused by the extraneous echoes. The measured water temperature is entered as an input yielding a speed of sound, which permits precise calculation of the arrival time.

Multipaths can also occur if multiple reflected signals from the sides of the frame interfere with the direct signal. Such interference can be eliminated by changing the pinging frequency, such that there is no overlap between the multiple reflections and the direct signal until the reflections have decreased to an insignificant level. The number of reflections required for the reflections to die away depends on the reflection coefficient of the intake sides where the arrays are mounted. For example, in the case of the smooth surface of the steel frame, the signals can persist for as many as eight reflections from each side. The ASFM operating software contains a function which calculates the pinging rate required at each level to avoid interference from multiple reflections.

Installation of the ASFM at Lower Granite

ASL Environmental Sciences Inc. was contracted by the Walla Walla District of the U.S. Army Corps of Engineers (USACE) to assist in the installation and operation of an ASFM in Unit 4 at the Lower Granite Dam (Fig. 3, 810 MW plant capacity) in December 2004 on the Snake River in Washington State. This installation is an example of a large, fixed-frame measurement for this 135 MW Kaplan unit with a 3 bay intake.

At Lower Granite Dam, two slots exist in the intake configuration for each unit. One slot is to accommodate a dewatering bulkhead and one slot to accommodate an emergency closure gate. Due to a requirement to divert juvenile fish out of the turbine intakes, the bulkhead slot is used to accommodate fish screening devices. Fish screens are in place from 1 April though 15 December each year. Fish screens are not required during the 15 Dec to 31 March time period. The goal of the turbine index testing was to develop operating cam curves for conditions with and without fish screens. Measurement of turbine discharge is a key element of the turbine index testing. For the Lower Granite testing, the frames were designed to fit in the emergency closure gate slot. The full intake for each turbine unit is divided into 3 intake bays, each with a bulkhead slot and emergency gate closure slot. Therefore to provide flow measurement, 3 frames were required to be deployed, one in each bay.

The ASFM measurements were done concurrently with measurements using Winter-Kennedy taps and the results are presented in Wittinger (2005). A cross section of the intake showing the measurement system is shown in Figure 7. The measurements were:

1) One on-cam and six off-cam conditions with the fish screens removed;
2) One on-cam and seven off-cam conditions with the fish screens installed.

Figure 3: Aerial view of Lower Granite Dam

Figure 4: Transducer support frame being moved to the deck for the installation of the ASFM components using a mobile crane

Figure 5: Transducer support frame rigged prior to installation into the gate slot

Figure 6: Detail of the switching canisters being mounted on the frame

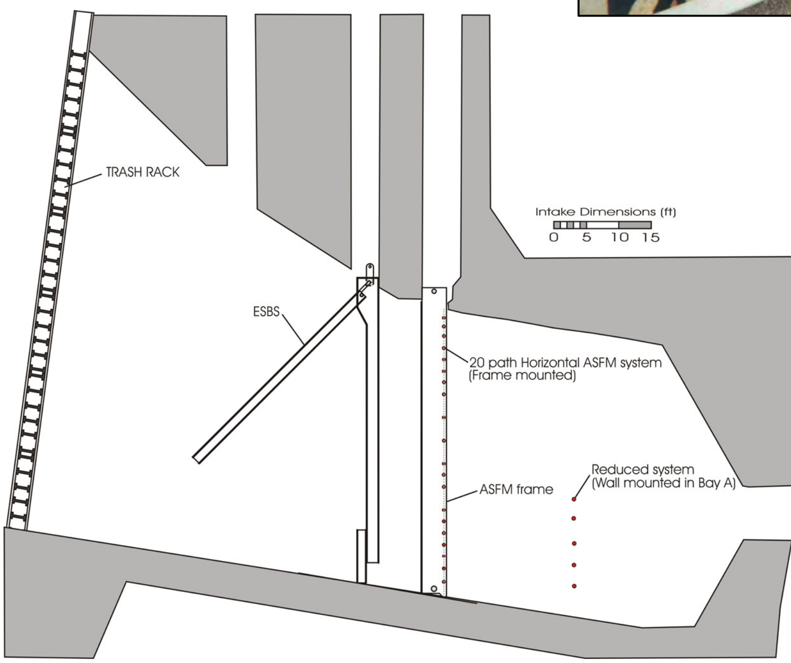

Figure 7: A cross section of the Lower Granite intake, showing the trash rack, fish screens and the 20-path system

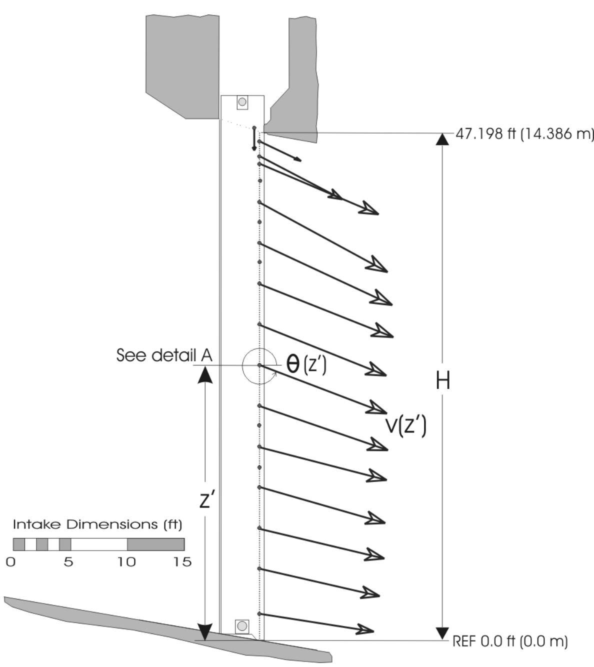

Figure 8: Location of the measurement plane, showing typical velocity vectors

Installation of the ASFM at the Edison Sault Electric Company

Edison Sault Electric Company (ESE), located in St. Marie Michigan, operates a plant with 74 horizontal shaft tandem-mounted camelback turbines of various manufacturers (Fig. 9). This plant, constructed from 1898 to 1902, generates 25 - 30 MW when fully on-line, about 225 GWhrs annually. The units are numbered 6 to 80. A spillway has been put in place of Unit 43. Each unit has a capacity of about 400 to 600 kW at 18 feet of net head. The plant was put in service around 1904. A narrow power canal widens into a forebay to feed each of the individual units. Originally, a trash rack had been mounted in the forebay that also had a flow straightening function. It had been removed because it was judged to be too costly to replace. Today, trash is removed manually as it collects near the south end of the plant.

ASL AQFlow Inc was contracted by ESE to conduct flow measurements with a transportable ASFM, collect free surface water elevation data and turbine characteristics and to use this data to construct performance (power, flow and efficiency) curves for each of the 74 units, and to provide information to prepare the priority table.

The ASFM was installed in the intakes of Units 6 through 80 (74 units with turbines) at Edison Sault Dam in October-November 2003. Each unit has one intake bay which was equipped with 10 acoustic horizontal paths. A side and top views of the units (Figures 10 and 11) show a schematic diagram of the ASFM as installed in the plant.

Frontal view of the water intakes: quarter mile long

Aerial view of the power canal and the plant

Electric generators

Aerial view of the tail race

Figure 9: Views of the Edison Sault Electric Plant

The transducer support frame was designed and supplied by Acres Manitoba Ltd., Winnipeg, MB, with some support from ASL AQFlow. Fig. 12 shows a frame being moved onto the deck prior to installation of the ASFM components. Fig. 13 shows the frame fully instrumented and ready to be inserted into the intake slot. Fig. 14 shows the location of the ASFM measurement plane in the intake.

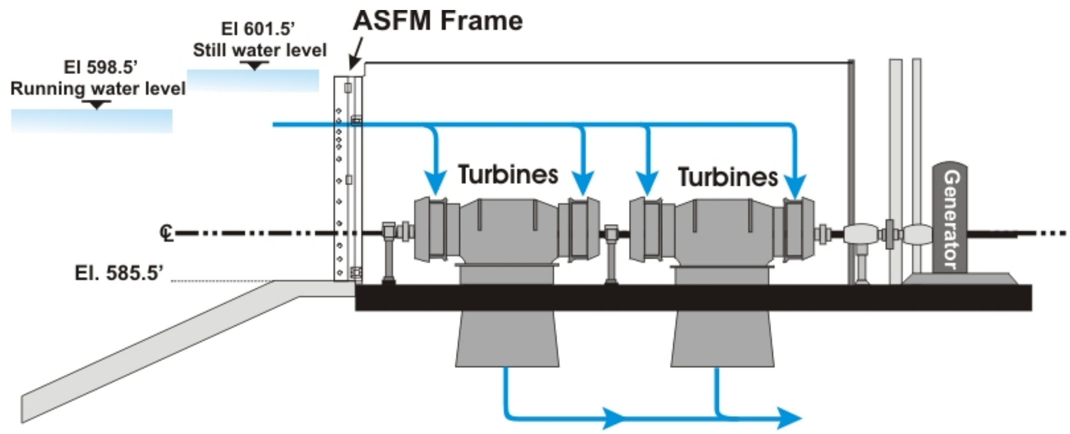

Figure 10: Side view of a unit at the Edison Sault plant showing the ASFM frame, turbines and generator

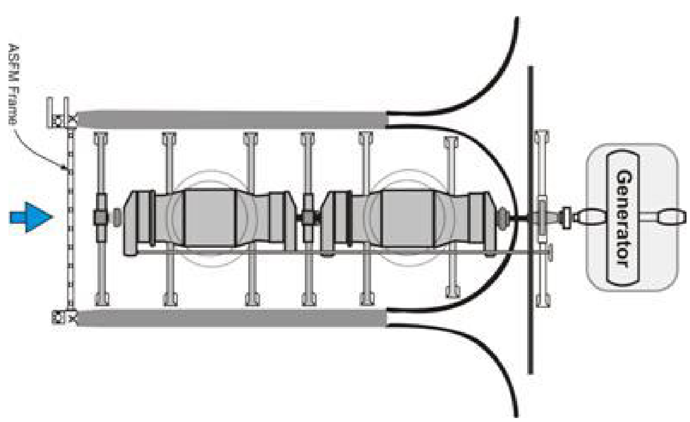

Figure 11: Top view

Figure 12: Transducer support frame being moved to the deck for the installation of the ASFM

Figure 13: Transducer support frame rigged prior to installation into the gate slot

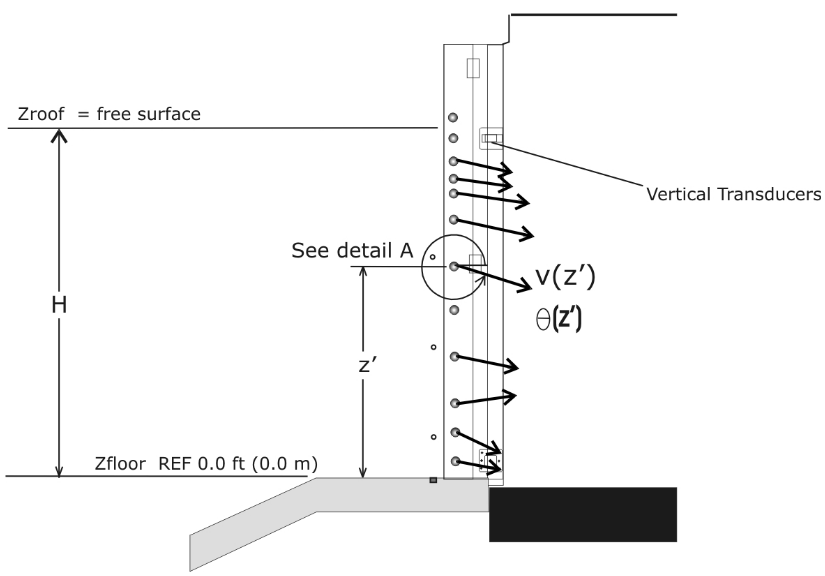

Figure 14: Location of the measurement plane in the intake, and definition of associated parameters

Measurements commenced on November 6, 2003 and continued until November 26. During this time, the frame was moved close to 90 times because some of the units were repeated.

Conclusions

It is possible to design ASFM frames for a variety of different kinds of units. Careful attention to detail is required to provide a stable, vibration free platform for measurements.

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