Comparison of the Acoustic Transient Time and Pressure - Time Discharge Measurements

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Abstract

The Magat Hydroelectric Power Plant (HPP), located on the Magat River—a significant tributary of the Cagayan River in Luzon, Philippines—plays a vital role in regional agriculture by providing irrigation water for vast areas of farmland. The dam and use of water for irrigation is managed by the Philippine National Irrigation Authority (NIA), and the power plant is currently owned and operated by SN Aboitiz Power (SNAP). Consequently, SNAP compensates the NIA for the water utilized in electricity generation, necessitating precise accounting of the water discharged by the HPP.

Originally, discharge measurement at the Magat HPP was conducted using a downstream weir. To enhance accuracy, Acoustic Travel Time (ATT) meters were later installed on each unit's penstock, comprising eight ATT sensors (arranged in four paths across two planes) supplied by Accusonic. These sensors continuously monitor discharge.
However, discrepancies between the weir and ATT meter readings prompted the involvement of Norconsult Norge AS to verify ATT readings using the Pressure-Time (PT) method. PT sensors were placed on all four unit’s penstocks in two sections, at distances of approximately 45 m, 50 m, and 27 m (for two units).

The paper discusses the measurements and the results of the comparative analysis of the ATT and PT discharge measurements. The findings are further corroborated by evaluating the head losses in the penstocks and the efficiencies of the turbines

1. Introduction

The Magat Dam is owned and operated by the National Government through the National Irrigation Administration (NIA) in the Philippines. NIA is responsible for managing and distributing water from the reservoir for agricultural irrigation in the surrounding areas, ensuring that farmers have access to a reliable water supply for their crops. The Magat Dam and Reservoir also serve as a flood control mechanism, mitigating the risk of downstream flooding. NIA plays a crucial role in monitoring and managing water levels in the reservoir to prevent excessive release during periods of heavy rainfall and reduce the impact of potential floods.

SN Aboitiz Power (SNAP) owns and operates the Magat Hydroelectric Power Plant (HPP), taking water from the Magat Dam. The Magat HPP has 4 units, each with a of capacity of 90 MW, rated net head of 81 m and rated flow of 127.9 m^3/s. The average annual output in the period 2009 to 2015 was 734.52 GWh.

SN Aboitiz is buying the water from NIA to produce electricity. Since water is a commodity that is purchased, it is necessary to measure of how much water is discharged in the production of electricity. To keep track of the amount of water consumed, SNAP has installed a 4-path ultrasonic flowmeter delivered from Accusonic, utilizing the method of Acoustic Travel Time (ATT).

To check the ATT discharge measurements, Norconsult was hired to perform Pressure-Time (PT) discharge measurements on each unit. The test was performed during the period 2023-03-02 to 2023-03-07 (for unit 1 and 3) and in the period 2023-06-17 to 2023-06-24 (for unit 2 and 4).

2. Brief Overview of the measurement methods

2.1 The Ultrasonic Acoustic Travel Time (ATT) method

The ATT method for measuring discharge relies on the principle that the velocity of an acoustic wave (typically ultrasonic) and the flow velocity are combined vectorially. This means that an acoustic pulse sent upstream will travel at a lower absolute speed compared to an acoustic pulse sent downstream. By measuring the time it takes for pulses to traverse in both directions, one can determine the average axial velocity of the fluid crossing the pulse path. It is important to conduct multiple time measurements to establish a time average and reduce random uncertainty. (Ref /1/).

An acoustic discharge measurement system consists of transducers placed in the measurement section. To operate the transducers, electronic equipment is necessary to conduct measurements, process the collected data, and display or record the results.

To compensate for transverse velocity components, it is recommended to use eight paths in two crossed planes. However, if the measuring section is located far from any upstream disturbances like bends or other factors that may cause asymmetry in velocity distribution such as swirls or large-scale turbulence, the number of paths can be reduced.

In the case of Magat HPP, where the penstock features a long straight section before the permanently installed flowmeters, four paths in two crossed planes were installed to measure the discharge.

2.2 The Pressure – Time method

The method of discharge measurement, also known as the "Gibson method," is founded on Newton's law and the principles of fluid mechanics. It establishes a relationship between the force resulting from the pressure difference between two measuring cross-sections in the penstock and the acceleration or deceleration of the water mass between these sections caused by the movement of a gate. The method measures the static pressure difference between two sections of a pipeline when the flow is stopped using a cut-off device like a turbine wicket gate. By integrating the time-varying pressure difference caused by the water hammer effect over a specific period, the flow rate can be determined.

3. Test Set-Up

3.1 The Acoustic measurements

The permanently installed measurement system was provided by Accusonic. The initial sensors were installed by an Accusonic technician, while the subsequent sensors were set up by the power plant's crew using Accusonic' procedures. The sensors were placed at the bottom of the 105 m long penstock, approximately five diameters upstream of the downstream bend. Eight sensors within the flowmeter were arranged in four crossed paths across two planes.
See figure 1.

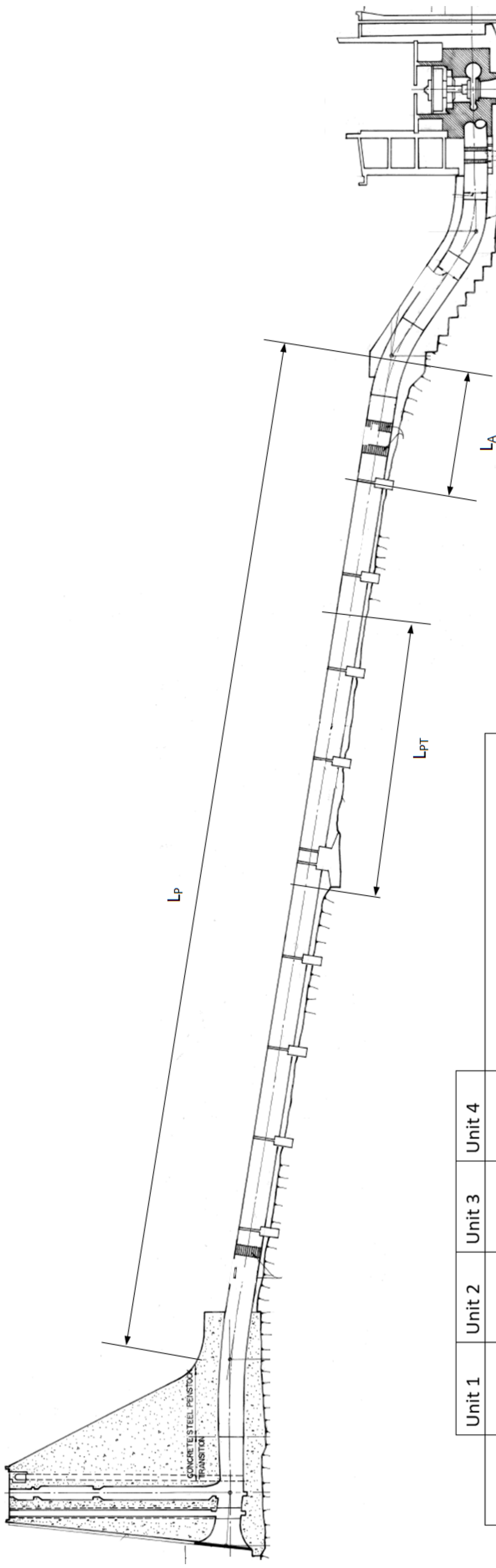
The signals from the transducers were processed by the Accusonic Flowmeter, which then transmitted the data to the power plant's SCADA system. The digital signals from the SCADA system were converted into mA-signals and continuously measured in Norconsult's data acquisition system, where they were recorded alongside other measured parameters.

3.1 The Pressure-Time measurements

PT sensors were placed on all four unit’s penstocks in two sections, at distances of approximately 45 m, 50 m, and 27 m (for two units). Two pressure sensors were placed at each section.

The pressure-time pressure was recorded with Norconsult's Impuls data acquisition unit for later filtering and calculations. The pressure time sections are shown in Figure 1. For each section two Druck PTX1830 pressure sensor were used. The pressures at the high pressure side and the low pressure side of the turbines and the generated power was also measured, enabling us to calculate the unit and turbine efficiency, see Figure 2.

The leakage through the wicket gates were found by measuring the sinking time of the water in the penstock, the intake gate being closed. Any leakage through the main gate was observed manually.



	Unit 1	Unit 2	Unit 3	Unit 4	
L_P	104.5 m	105. m	105.5 m	106.0 m	Measured from upper to lower bend
L_A	≈ 5 pipe diameters				
L_{PT}	27 m	45 m	27 m	50 m	
D	5.8 m	5.8 m	5.8 m	5.8 m	

Figure 1 The Penstock

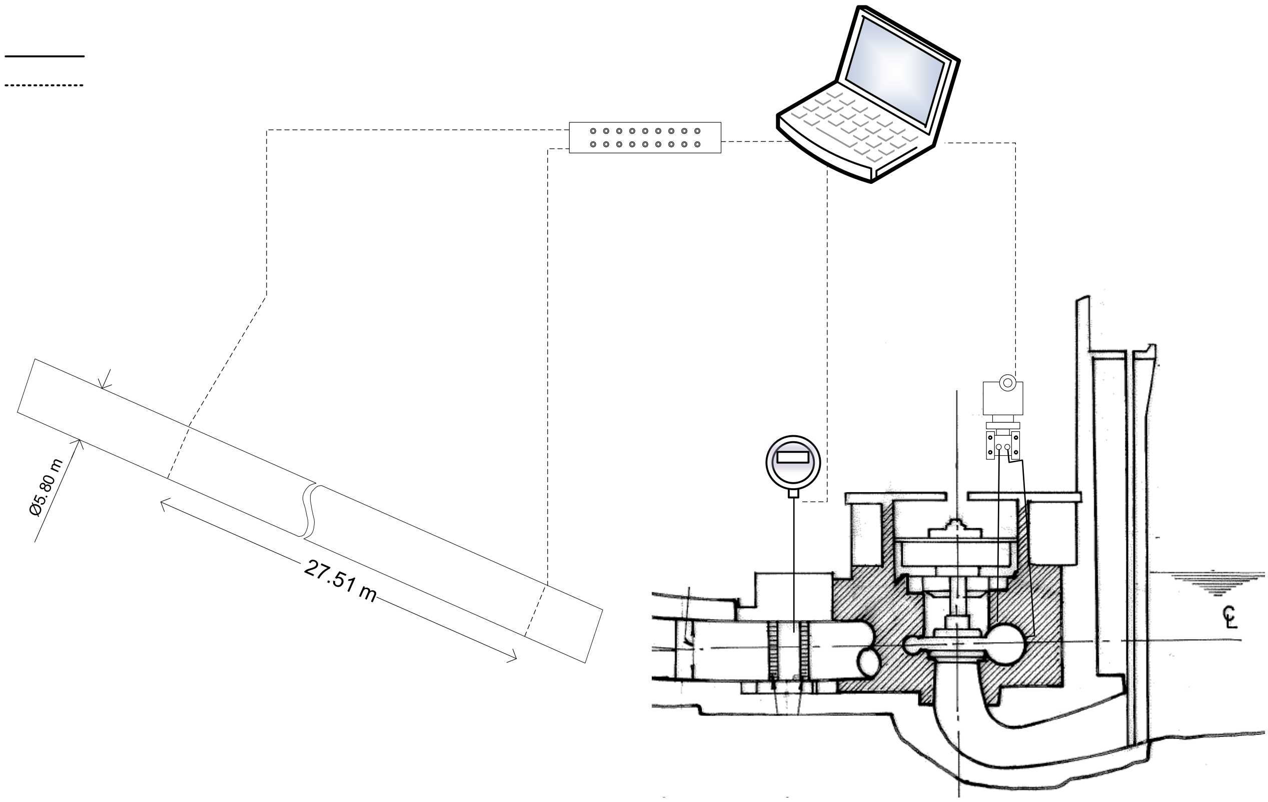


Figure 2 Penstock. Instrumentation for pressure time measurements.

4. Results and Analysis

Figure 3 below shows the deviation between the discharge measured with the pressure time method (Q_{PT}) minus the discharge measured with the Acoustic travel time method (Q_{ATT}) versus the discharge measured with the Acoustic travel time method. The statistics are given in Table 1 on page 4.

Table 1 Tabulated values

	Average deviation		Standard deviation
	[m³/s]	[%]	[m³/s]
Unit 1	2.52	3.12 %	0.73
Unit 2	0.27	0.44 %	0.28
Unit 3	1.19	1.56 %	0.32
Unit 4	-0.03	-0.05 %	0.10

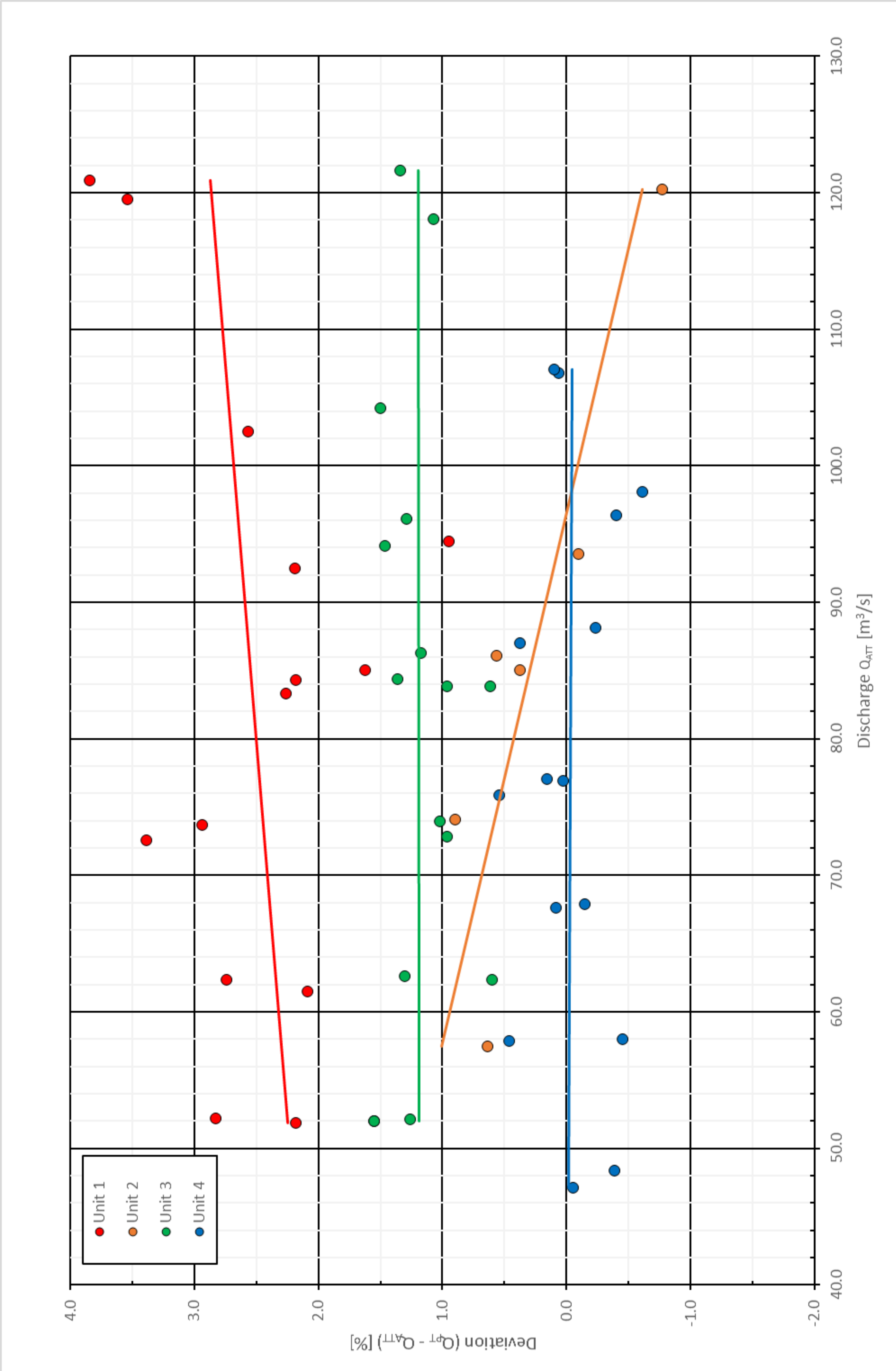


Figure 3 Deviation ($Q_{PT} – Q_{ATT}$) vs. Q_{ATT}

4. Discussion about the measurements

Unit 1 and unit 3 have the shortest reach -- both 27 m -- while unit 2 and unit 4 have 45 m and 50 m respectively, see table on Figure 1. It is interesting to note that the units with the longest measuring reach have the lowest average deviation between the discharge measured with ATT and PT method, although no conclusion can be taken from this.

The measurements on unit 1 was problematic, as the guide vanes opened due to an error in the governor. The guide vanes opened a little after 5 seconds, see Figure 4. This made it difficult to determine the value of the zero after the measurements, hence the spreading of the average deviation is 2 to 3 times higher than for the other units and therefore the uncertainties are higher.

The measurements at unit 3 was somewhat amputated, as a component in the excitation system broke down for each stop and had to be replaced by spare parts.

The uncertainty in the PT flow measurements for unit 2, 3 and 4 is estimated to be ± 0.9%. For unit 1 the uncertainty is higher and is estimated to be ± 1.7%.

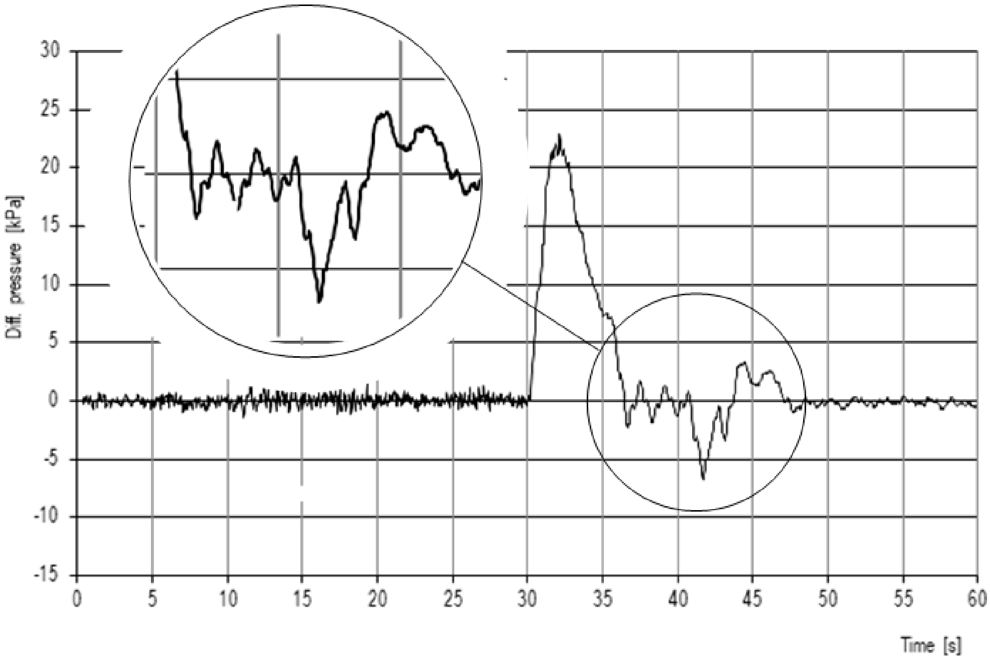


Figure 4 The differential pressure on unit 1

References

[1] *IEC 60041 ED4 "Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines" Committee Draft 2022-12-16.*