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Department of Water Resources, River Development and Ganga Rejuvenation

TECHNICAL MEMORANDUM

ON

CALIBRATION & TESTING OF CLOSED CONDUIT FLOW MEASUREMENTS

by

Dr M. Selva Balan, Additional Director
Dr. K. Kumar, Scientist 'D'
Smt. Lata Gupta, Scientist 'D'
S. Ajai, Scientist 'C'
K.U. Farande, Scientist 'B'

HYDRAULIC MACHINERY, CAVITATION AND INSTRUMENTATION DIVISION

Dr. PRABHAT CHANDRA
DIRECTOR

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खड़कवासला,पुणे–411 024

CENTRAL WATER AND POWER RESEARCH STATION
Khadakwasla, Pune - 411 024

PREFACE

Accurate measurement of water flow forms the technical backbone of effective water resources management, infrastructure performance evaluation, and transparent governance. In the context of India's increasing water stress, expanding hydraulic infrastructure, and implementation of large-scale national water programmes, reliable and traceable flow measurement has become indispensable for planning, execution, monitoring, and auditing of water-related projects.

The Central Water and Power Research Station (CWPRS), Pune, as a premier national research and testing institution under the Ministry of Jal Shakti, has been entrusted with the responsibility of providing scientific and metrologically traceable flow measurement services. The Hydraulic Machinery Division of CWPRS plays a pivotal role in calibration, testing, field investigations, and performance evaluation of flow measuring instruments, pumps, and hydraulic systems supporting drinking water supply, irrigation, power generation, and industrial applications.

This Technical Memorandum has been prepared to document the principles, methodologies, facilities, and practical challenges associated with the calibration and testing of closed conduit flow elements. It also highlights the importance of flow measurement in the effective implementation of various national schemes of the Ministry of Jal Shakti, including Jal Jeevan Mission, Namami Gange Programme, Atal Bhujal Yojana, National Water Mission, and other allied initiatives.

The memorandum consolidates laboratory-based primary calibration techniques, field-level secondary calibration practices, pump testing methodologies, and installation-related issues affecting measurement accuracy. It is intended to serve as a technical reference for engineers, planners, utilities, and implementing agencies involved in water supply, irrigation, hydropower, and industrial water management.

Dr. Prabhat Chandra
Director

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The authors also acknowledge the valuable contributions of officers and staff of the Hydraulic Machinery Division, whose extensive experience in flow measurement, calibration, pump testing, and field investigations has enriched the technical content of this document. Their assistance in laboratory experiments, field studies, data analysis, and documentation is gratefully acknowledged.

Appreciation is extended to officials of the Ministry of Jal Shakti, Central Water Commission, State Water Resources Departments, Urban Local Bodies, and other stakeholder organizations for their continued interaction, technical inputs, and cooperation, which have helped align this memorandum with practical field requirements and national programme objectives.

The cooperation extended by manufacturers, utilities, and agencies during calibration, testing, and site investigations is also duly acknowledged.

EXECUTIVE SUMMARY

Accurate and reliable flow measurement is a fundamental requirement for efficient water management, infrastructure performance assessment, and transparent implementation of national water programmes. In India, where water resources are limited and demands across domestic, agricultural, industrial, and energy sectors continue to rise, scientific measurement of flow in closed conduits is critical for sustainable and accountable utilization of water.

This Technical Memorandum presents a comprehensive overview of the calibration and testing of closed conduit flow elements, with particular emphasis on laboratory-based primary calibration methods, field-level secondary calibration techniques, and practical challenges encountered during site installations. The document has been prepared by the Hydraulic Machinery Division of CWPRS, which operates nationally recognized gravimetric and volumetric calibration facilities conforming to ISO standards and NABL traceability requirements.

The memorandum highlights the role of flow measurement in major national schemes of the Ministry of Jal Shakti, including Jal Jeevan Mission, Namami Gange Programme, Pradhan Mantri Krishi Sinchayee Yojana, Atal Bhujal Yojana, National Water Mission, and Dam Rehabilitation and Improvement Programme. Across these initiatives, accurate flow data is essential for service verification, water accounting, performance monitoring, energy efficiency, regulatory compliance, and environmental protection.

Detailed descriptions of gravimetric and volumetric primary calibration techniques are provided, along with their governing standards, uncertainty considerations, and applicability. The document also discusses secondary calibration methods, particularly the use of ultrasonic clamp-on flow meters for on-site verification of large pipelines where laboratory calibration is not feasible.

In addition, the memorandum documents submersible pump testing methodologies, flow meter classifications, and the impact of installation effects such as inadequate straight lengths, upstream disturbances, and flow profile distortions on measurement accuracy. Experimental studies on installation effects of clamp-on ultrasonic flow meters under various piping configurations are presented to demonstrate the extent of errors arising from non-ideal site conditions.

The Technical Memorandum serves as a practical technical reference for engineers, utilities, and implementing agencies involved in water supply, irrigation, hydropower, and industrial water systems. It reinforces the importance of correct meter selection, proper installation, periodic calibration, and uncertainty evaluation to ensure reliable flow measurement and effective water governance.

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CHAPTER 1
INTRODUCTION

Water is the foundation of life, livelihood, and national security. In a country like India—characterized by rapid population growth, increasing urbanization, climate variability, and rising pollution pressures—every drop of water is valuable. Water is a finite and precious resource that underpins human survival, public health, agriculture and food security, industrial growth, energy generation, ecosystems, and biodiversity. Beyond being a natural resource, water in India represents a social, economic, and strategic asset.

1.1 IMPORTANCE OF WATER AND ITS MEASUREMENT

India faces inherent constraints in freshwater availability, with less than one percent of global freshwater resources being readily usable, coupled with highly uneven spatial and temporal distribution. Over-extraction of groundwater, growing domestic and industrial demand, and increasing stress on surface water systems have further intensified water scarcity. Consequently, water resources must be measured accurately, conserved effectively, stored prudently, reused efficiently, and managed scientifically.

Water security is directly linked to public health, poverty alleviation, social stability, and economic development. India supports nearly 18 percent of the world's population with only about 4 percent of global freshwater resources, making efficient water management an absolute necessity. The country's strong dependence on monsoon rainfall introduces additional uncertainty, particularly for rural livelihoods and agricultural productivity. Urban areas face parallel challenges, including intermittent supply, leakage losses, inequitable distribution, and declining source sustainability.

To meet the growing demands of a developing economy, India's water resources must be harnessed judiciously through integrated development, conservation, and management. Water is required across multiple sectors, including irrigation, livestock and fisheries, drinking and domestic use, sanitation and hygiene, industrial processing and cooling, power generation, manufacturing, environmental flows, wetlands, aquatic ecosystems, and groundwater recharge.

Climate change is significantly altering the hydrological cycle, resulting in erratic rainfall patterns, increased frequency of floods and droughts, glacier retreat affecting river regimes, and higher evaporation losses. While rainfall remains the primary source of freshwater in India—recharging rivers, reservoirs, and aquifers—it is increasingly characterized by short-duration, high-intensity events that cause runoff and flooding rather than effective storage.

This highlights the critical importance of rainwater harvesting, storage infrastructure, and regulated utilization**.**

Access to clean and safe water is essential for human dignity, improved quality of life, and prevention of water-borne diseases. Provision of safe drinking water is both a constitutional obligation and a moral responsibility of the State. However, untreated sewage, industrial effluents, agricultural runoff, and solid waste dumping continue to degrade surface and groundwater resources. Pollution reduces the availability of usable water and intensifies the need for scientific planning, monitoring, and regulation.

Across the programs of the **Ministry of Jal Shakti**, **accurate flow measurement** forms the backbone of accountable and transparent water management. Whether for drinking water supply, irrigation, river rejuvenation, groundwater sustainability, or environmental protection, reliable flow data is a technical prerequisite for performance monitoring, regulatory compliance, auditing, and long-term water security**.** Flow measurement transforms water management from estimation-based practices to evidence-driven decision-making, enabling efficient use, equitable distribution, environmental protection, and climate resilience.

The **Central Water and Power Research Station (CWPRS)** serve as a national backbone institution in this domain by providing **primary standard flow measurement facilities, calibration services, technical guidance and research support.** CWPRS ensures that flow data used under national water programs is **accurate, traceable, reliable, and fit for governance, planning, and public accountability.** Without accurate flow measurement, sustainable water management is not achievable.

Sustainable water management requires an integrated approach encompassing:

- Conservation and storage
- Accurate measurement and continuous monitoring
- Pollution control
- Efficient use and reuse
- Strong institutional and technical support

CWPRS in conjunction with Government initiatives under the Ministry of Jal Shakti, play a pivotal role in securing water for present and future generations.
CWPRS contributes by:

- Developing and validating flow measurement techniques
- Calibrating water and flow-measuring instruments
- Conducting hydraulic model studies for rivers, reservoirs, barrages, canals, and spillways

- Supporting water distribution planning, flood management, and interlinking of rivers
- Providing technical support to the Ministry of Jal Shakti, CWC, NWDA, State Water Resources Departments, and Urban Local Bodies

Key national initiatives of the Ministry of Jal Shakti—such as the **Jal Jeevan Mission (JJM), Namami Gange Programme (NGP), Atal Bhujal Yojana (Atal Jal), AMRUT/AMRUT 2.0,** and the **National Water Mission—**emphasize accurate measurement, monitoring, conservation, reuse, and sustainability. Together, these efforts reinforce the central role of scientific flow measurement in achieving water security, environmental protection, and sustainable development**.**

1.2 NATIONAL SCHEMES

1.2.1 Jal Jeevan Mission (JJM)

This scheme aims to provide functional household tap water connections to every rural household with adequate quantity and prescribed quality. It focuses on sustainability of water sources, water quality monitoring, and community participation.

The Jal Jeevan Mission emphasizes measurement, monitoring, and accountability in drinking water supply systems. The Division supports JJM through:

- Calibration of bulk water meters and flow meters used in rural water supply schemes
- Performance testing of pumps for energy-efficient and reliable water delivery
- Field verification of flow measurement installations to reduce non-revenue water

These services ensure accurate reporting of water supplied to habitations and support sustainable operation of JJM infrastructure.

1.2.2 Namami Gange Programme (NGP)

Namami Gange is an integrated mission for conservation, rejuvenation, and pollution abatement of River Ganga. It includes sewage treatment, river surface cleaning, ecological restoration, and public awareness.

1.2.3 Atal Bhujal Yojana (Atal Jal)

This scheme promotes sustainable groundwater management through community participation in water-stressed areas. It emphasizes demand-side interventions, aquifer mapping, and data-driven groundwater regulation.

1.2.4 Swachh Bharat Mission (Gramin) – Water Component

The scheme ensures safe management of solid and liquid waste to prevent water source contamination. It supports protection of drinking water sources and improved rural sanitation.

1.2.5 National Aquifer Mapping and Management Programme (NAQUIM)

NAQUIM aims to map and characterize aquifers across the country using scientific techniques. The generated data supports evidence-based groundwater management and planning.

1.2.6 National Water Mission (NWM)

This mission focuses on increasing water use efficiency by 20 percent across sectors. It promotes basin-level integrated water resource management and conservation practices. One of the core objectives of the National Water Mission is improving water use efficiency by at least 20 percent.

The Division contributes by:

- Evaluating and improving pump efficiencies
- Optimizing hydraulic design of pumping and conveyance systems
- Conducting water audits through accurate flow measurement and calibration

These interventions directly reduce water losses and energy consumption across irrigation, municipal, and industrial sectors.

1.2.7 Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)– Water Resources Component

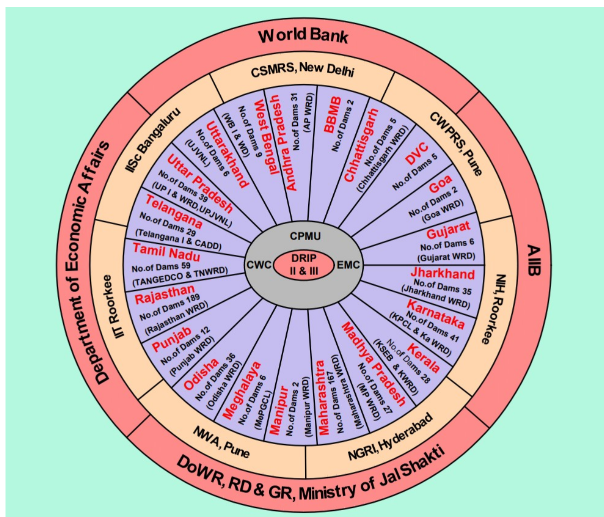
The scheme aims at efficient irrigation management and "more crop per drop." It integrates surface water, groundwater, and micro-irrigation practices.

1.2.8 Dam Rehabilitation and Improvement Programme (DRIP)

DRIP focuses on improving the safety, performance, and sustainability of existing dams. It strengthens dam monitoring, instrumentation, and emergency preparedness.

Under the Dam Rehabilitation and Improvement Project, accurate measurement of releases, efficient pumping, and hydraulic safety of appurtenant systems are critical. The Division supports DRIP through:

- Calibration of flow measuring devices associated with dam outlets and water conveyance systems
- Field measurement of discharge for performance verification
- Surge analysis and transient studies to ensure safety of pumping and pipeline systems downstream of dams



The Division's expertise assists dam authorities in evidence-based decision-making for rehabilitation and modernization works.

1.2.9 Alignment with Ministry of Jal Shakti Initiatives

The activities of the Hydraulic Machinery Division are closely aligned with the objectives and implementation needs of major national initiatives of the **Ministry of Jal Shakti**.

CHAPTER 2

IMPORTANCE OF FLOW MEASUREMENT IN NATIONAL SCHEMES

Under various schemes implemented by the Ministry of Jal Shakti (MoJS), accurate flow measurement is a fundamental technical requirement for service verification, water accounting, operational efficiency, and regulatory compliance. Reliable flow data enables objective performance assessment, transparency, and accountability in public water infrastructure. Flow measurement plays a critical role across drinking water supply, irrigation, river rejuvenation, groundwater management, and flood control programs. The importance of flow measurement in major national schemes is outlined below.

2.1 JAL JEEVAN MISSION (JJM) – RURAL DRINKING WATER SUPPLY (Department of Drinking Water & Sanitation, MoJS)

The Jal Jeevan Mission aims to provide adequate, safe, and sustainable drinking water to all rural households through Functional Household Tap Connections (FHTCs). Flow measurement is central to verifying service delivery and ensuring sustainability. Flow Measurement is required to:

- Verification of Functional Household Tap Connections (FHTCs)
- Measurement of quantity of water supplied in terms of litres per capita per day (LPCD)
- Monitoring bulk water supply from sources, treatment plants, and service reservoirs
- Detection of leakages, losses, and inequitable distribution within distribution networks
- Integration with IoT- and SCADA-based dashboards for real-time service-level monitoring

Typical Locations for Flow Measurement are raw water intake and transmission mains, Treated water transmission pipelines, Overhead service reservoir outlets, and Village-level and intra-village distribution pipelines.

2.2 NATIONAL PROGRAMME ON DRINKING WATER (INCLUDING LEGACY NRDWP SYSTEMS) (Department of Drinking Water & Sanitation, MoJS)

Several drinking water systems developed under earlier programmes require performance evaluation and optimization. Flow Measurement is required to:

- Assessment of operational performance of legacy systems
- Rationalization of pumping schedules and energy consumption
- Validation of rehabilitation, retrofitting, and augmentation works

- Audit of actual supplied discharge against design discharge

2.3 PRADHAN MANTRI KRISHI SINCHAYEE YOJANA (PMKSY – HAR KHET KO PANI) (Department of Water Resources, River Development & Ganga Rejuvenation)

PMKSY focuses on expanding irrigation coverage and improving water use efficiency. Flow Measurement is required to:

- Measurement of irrigation releases through canals and pressurized pipelines
- Ensuring equitable water distribution across command areas
- Performance evaluation of lift irrigation and micro-irrigation systems
- Monitoring of water use efficiency and crop-wise allocation

Typical Applications are Pressurized irrigation pipelines, Lift irrigation delivery mains and Canal outlets and field-level discharge points.

2.4 NAMAMI GANGE PROGRAMME (NGP) (National Mission for Clean Ganga – NMCG)

Flow measurement is essential for pollution abatement and river health restoration under NGP. Flow Measurement is required to:

- Measurement of sewage flows in sewer networks and at STP inlets and outlets
- Monitoring of treated effluent discharge into rivers
- Assessment of environmental flows (e-flows)
- Compliance monitoring against pollution load reduction targets

Application areas are: Sewerage networks, Sewage treatment plants (STPs) and pumping stations and River inflow and outflow monitoring locations.

2.5 NATIONAL RIVER CONSERVATION PLAN (NRCP)

(Now subsumed under NMCG for major rivers)

Flow Data is required to:

- Quantification of polluted discharges entering rivers
- River health assessment and trend analysis
- Performance monitoring of interception, diversion, and treatment works

2.6 ATAL BHUJAL YOJANA (ATAL JAL) (Department of Water Resources, River Development & Ganga Rejuvenation)

Although primarily focused on groundwater management, flow measurement plays an indirect but significant role to:

- Measurement of groundwater abstraction through piped water supply systems
- Monitoring of community-managed bulk water distribution
- Validation of demand-side water management interventions

Focus Areas are Bulk abstraction and delivery pipelines and Community-level water budgeting and accounting exercises

2.7 HYDROLOGY PROJECT (PHASE II)
(Department of Water Resources, River Development & Ganga Rejuvenation)

The Hydrology Project emphasizes development of robust, integrated water data systems. Core Importance of Flow Measurement are Development of quantitative and reliable hydrological databases, Calibration and validation of hydrological and hydraulic models and Integration of flow data from rivers, canals, and pipelines. Surface water flow measurement supports planning and operation of drinking water supply, irrigation, and flood management schemes.

2.8 FLOOD MANAGEMENT AND RIVER BASIN MANAGEMENT PROGRAMMES
(Department of Water Resources, River Development & Ganga Rejuvenation)

Flow Measurement is Essential to Measurement of controlled releases through dams, barrages, and gated structures, Monitoring of pipeline-based flood diversion and drainage systems and Basin-level water balance and flood risk assessment studies.

Across all national water-related schemes, accurate and reliable flow measurement forms the technical foundation for planning, implementation, monitoring, auditing, and governance. Flow measurement transforms water infrastructure into measurable, accountable, and performance-driven systems. Institutions such as CWPRS play a vital role in ensuring that flow measurement systems are accurate, traceable, and scientifically robust, thereby supporting effective implementation of Ministry of Jal Shakti programs and long-term water security.

CHAPTER 3
FLOW MEASUREMENT TECHNIQUES

The Hydraulic Machinery Division of CWPRS was established in 1984 under the UNDP programme and has been functioning as a national-level facility for calibration, testing, field investigations, and hydraulic performance evaluation. The Division functions as a specialized centre for calibration / testing, experimental research, field investigations, and technical consultancy, providing support to various Central and State Government departments, PSUs, and strategic infrastructure projects in the water, irrigation, power, and industrial sectors.

The Division operates Gravimetric and Volumetric Calibration Laboratories conforming to ISO 4185 and 8316 respectively. This division undertakes:

- Calibration of flow meters and water meters
- Testing of filters for pressure drop characteristics
- Head loss–discharge testing of valves
- Performance testing of submersible and rotodynamic pumps

3.1 MAJOR FACILITIES INCLUDE:

(a) Gravimetric Calibration Facility

- Maximum line size: 1000 mm (extendable up to 3000 mm)
- Maximum flow rate: 7200 m³/hr
- Calibration uncertainty: ±0.3%
- Weighing tank capacity: 100 tonnes

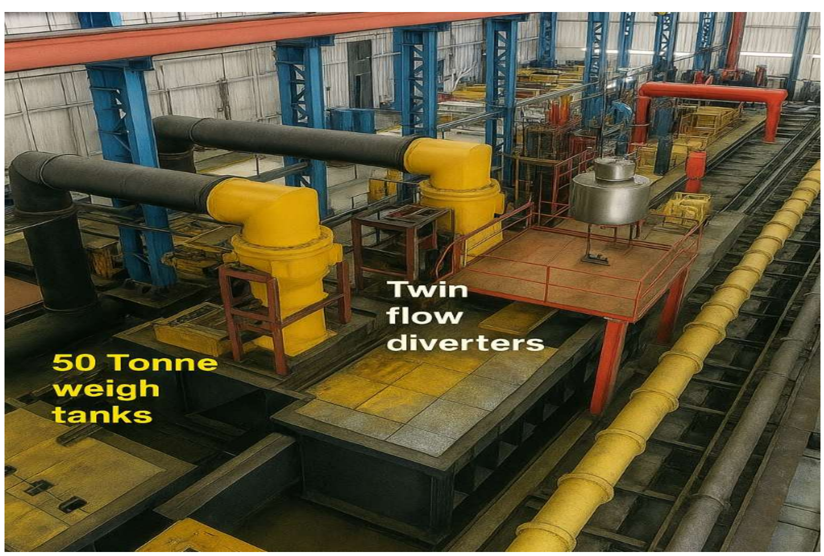


Figure 3.1: Gravimetric Calibration Laboratory at CWPRS

(b) Volumetric Calibration Facility

- Maximum line size: 250 mm NB
- Maximum flow rate: 250 m^3/hr
- Calibration uncertainty: ±0.5%
- Volumetric tank capacity: 3.862 m^3

Figure 3.2: Volumetric Calibration Laboratory at CWPRS

3.2 METHODS OF CALIBRATION:

Calibration is a critical metrological activity performed to establish a documented relationship between the values indicated by a measuring instrument and the corresponding values realized by reference standards, in accordance with the requirements of ISO/IEC 17025. In the domain of flow measurement, calibration methodologies are broadly classified into primary and secondary calibration techniques, based on the nature of the reference standard and the degree of metrological traceability achieved.

3.2.1 Primary calibration methods realize the flow quantity directly from fundamental SI units such as mass, volume, and time, without reliance on another calibrated flow-measuring device. These methods form the highest level in the traceability chain and are essential for establishing and maintaining national and laboratory reference standards.

Primary calibration services are typically carried out using gravimetric and volumetric standards under controlled laboratory conditions. In gravimetric calibration, the flow rate is determined by measuring the mass of the fluid collected over a precisely measured time interval, with corrections applied for fluid density, buoyancy, and environmental conditions. Volumetric calibration involves the collection of fluid in a calibrated volumetric tank or prover, where the volume is traceable to length standards. Both methods enable precise estimation of measurement uncertainty and ensure unbroken traceability to national or international standards, as mandated by NABL accreditation criteria.

3.2.2 Secondary calibration, on the other hand, is performed using reference instruments that are themselves calibrated against primary standards, and is particularly suited for field applications where primary standards cannot be deployed. In accordance with ISO/IEC 17025 principles, secondary calibration ensures traceability through a documented calibration hierarchy.

Ultrasonic clamp-on flowmeters are widely employed for on-site secondary calibration due to their non-intrusive nature and ability to measure flow under actual operating conditions. While the achievable uncertainty in secondary calibration is generally higher than that of primary methods, it provides a practical and reliable means for verification, performance assessment, and periodic validation of installed flow measurement systems, provided that uncertainty budgets, environmental influences, and method limitations are adequately evaluated and documented.

Table 3.1: Primary Methods of Calibration

Calibration of Flow Meters	Calibration Category	Method / Technique	Description
Establishes relationship between indicated values and reference standards as per ISO/IEC 17025.	Primary Calibration Methods (Direct realization of flow using SI units; highest level of traceability)	Gravimetric Method	Flow determined by mass collected over time; lowest measurement uncertainty.
		Volumetric Method	Flow determined using calibrated volumetric tanks or provers.
	Secondary Calibration Methods (Uses reference instruments calibrated against primary standards.)	Reference Meter Method (Ultrasonic Clamp-On Flow Meter)	Comparison with pre-calibrated reference flow meter. Non-intrusive on-site calibration suitable for large pipelines.

3.3 GRAVIMETRIC CALIBRATION TECHNIQUE

(As per ISO 4185 – Measurement of liquid flow in closed conduits — Weighing method)

3.3.1 Principle of Gravimetric Calibration

The gravimetric calibration technique is a primary calibration method in which the flow rate of a liquid is determined by direct measurement of mass collected over a precisely measured time interval. As specified in ISO 4185, this method establishes flow rate based on fundamental SI units of mass (kg) and time (s), without reliance on any previously calibrated flow-measuring device. Because of this direct realization, gravimetric calibration provides very high accuracy and low measurement uncertainty, making it suitable as a reference standard in accredited laboratories.

3.3.2 Measurement Equation

According to ISO 4185, the mass flow rate $\dot{m}$ is given by:

$$\dot{m} = \frac{M}{t}$$

Where:

- M = mass of liquid collected (kg)
- t = collection time (s)

The corresponding volumetric flow rate is obtained as:

$$Q = \frac{M}{\rho \cdot t}$$

Where ρ = density of the liquid at measured temperature (kg/m³)

3.3.3 Major Components of a Gravimetric Standard

A gravimetric calibration system typically consists of:

- Test Flow Line with device under test (DUT)
- Flow Control Valve for stabilizing flow
- Diverter System to start/stop collection without disturbing flow
- Weighing Tank or container
- Precision Weighing Balance / Load Cells
- High-accuracy Timer synchronized with the diverter
- Temperature Sensors for density correction
- Data Acquisition System

3.3.4 Operating Procedure (ISO 4185 Aligned)

1. Establish steady flow through the test section.
2. Divert the flow into the weighing tank using a fast-acting diverter.
3. Simultaneously start the timing system.
4. After a predefined duration, divert the flow back to bypass and stop timing.
5. Measure the collected mass using calibrated weighing equipment.
6. Apply corrections for:
    - Air buoyancy
    - Liquid density variation
    - Temperature effects
7. Compute flow rate and associated measurement uncertainty.

3.3.5 Measurement Uncertainty Considerations

ISO 4185 emphasizes evaluation of uncertainty contributions from:

- Mass measurement
- Timing accuracy
- Density determination
- Repeatability of flow
- Diverter response time

When properly designed, gravimetric systems can achieve expanded uncertainties better than ±0.1% (k = 2), depending on flow range and system design.

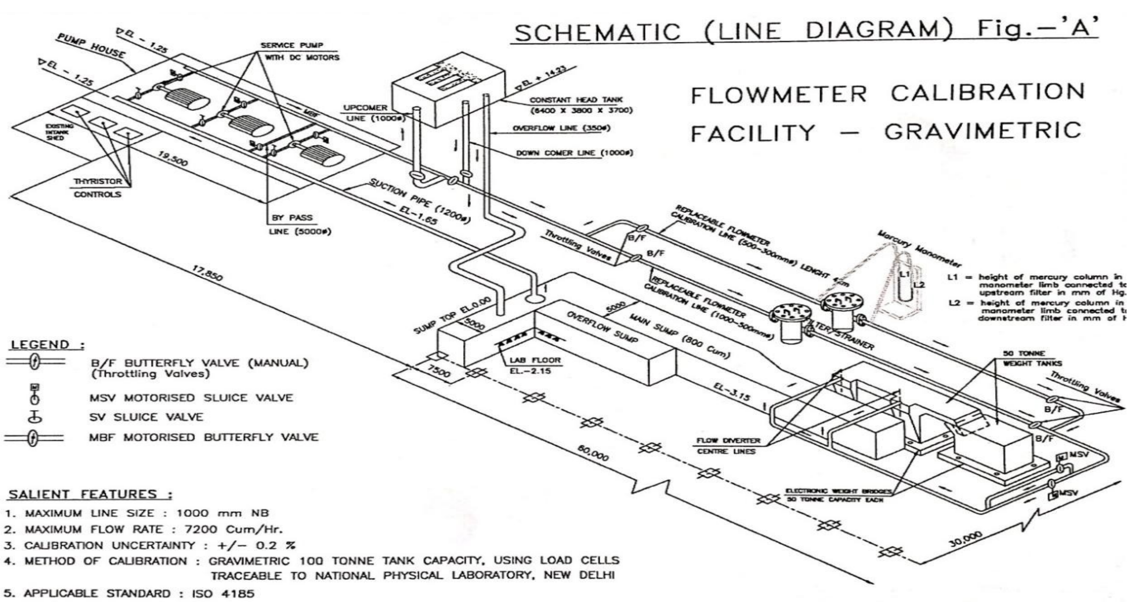


Figure 3.3: Schematic layout of Gravimetric Calibration Standard

3.3.6 Key Advantages (ISO / NABL Perspective)

- Direct traceability to SI units
- No dependence on reference flow meters
- Suitable for establishing primary calibration facilities
- Fully compliant with ISO/IEC 17025 traceability requirements

3.3.7 Typical Applications

- Calibration of electromagnetic, ultrasonic, turbine, and differential pressure flow meters
- Establishment of national or laboratory reference standards
- Verification of secondary and field calibration systems

3.4 VOLUMETRIC CALIBRATION TECHNIQUE

(As per ISO 8316 – Measurement of liquid flow in closed conduits — Volumetric method)

3.4.1 Principle of Volumetric Calibration

The volumetric calibration technique is a primary flow calibration method in which the volumetric flow rate is determined by direct measurement of the volume of liquid collected over a precisely measured time interval. As specified in ISO 8316, this method realizes flow directly from the fundamental SI units of length (volume derived) and time, without dependence on a reference flow meter. Due to its direct traceability and simplicity, volumetric calibration is widely used in accredited laboratories for achieving high accuracy in liquid flow measurements.

3.4.2 Measurement Equation

According to ISO 8316, the volumetric flow rate is expressed as:

$$Q = \frac{V}{t}$$

Where:

- Q = volumetric flow rate (m^3/s or m^3/h)
- V = volume of liquid collected in the calibrated volumetric tank (m^3)
- t = collection time (s)

If required, mass flow rate may be derived using:

$$\dot{m} = \rho . Q$$

Where ρ is the liquid density at measured temperature

3.4.3 Major Components of a Volumetric Standard

A typical volumetric calibration facility consists of:

- Supply Tank / Constant Head Tank
- Test Flow Line with Device Under Test (DUT)
- Flow Control Valve
- Pepper pot & Baffle plates for uniform water level rise
- Calibrated Volumetric Tank
- Level Measurement System (graduated scale, sight glass, or level sensors)
- High-accuracy Timer
- Temperature Sensors
- Drain / Return System

The volumetric tank is calibrated against dimensional standards, ensuring traceability to national length standards, as required by NABL.

3.4.4 Operating Procedure (ISO 8316 Aligned)

1. Establish stable and steady flow through the test section.
2. Ensure the volumetric tank is empty or at reference zero level.
3. Divert flow into the volumetric tank using a fast-acting diverter.
4. Start timing simultaneously with the diversion.
5. After a predefined duration, divert flow back to bypass and stop timing.
6. Record the collected volume from the calibrated tank scale or level system.
7. Apply corrections for:
   - Thermal expansion of tank
   - Liquid temperature variation
   - Meniscus and reading resolution
8. Calculate flow rate and associated measurement uncertainty.

3.4.5 Measurement Uncertainty Considerations

As emphasized in ISO 8316, uncertainty evaluation should include contributions from:

- Volume calibration of the tank
- Reading resolution of the level scale
- Timing accuracy
- Temperature effects on tank and liquid
- Repeatability of flow

Well-designed volumetric systems typically achieve expanded uncertainties of ±0.2% to ±0.5% (k = 2), depending on size and flow range.

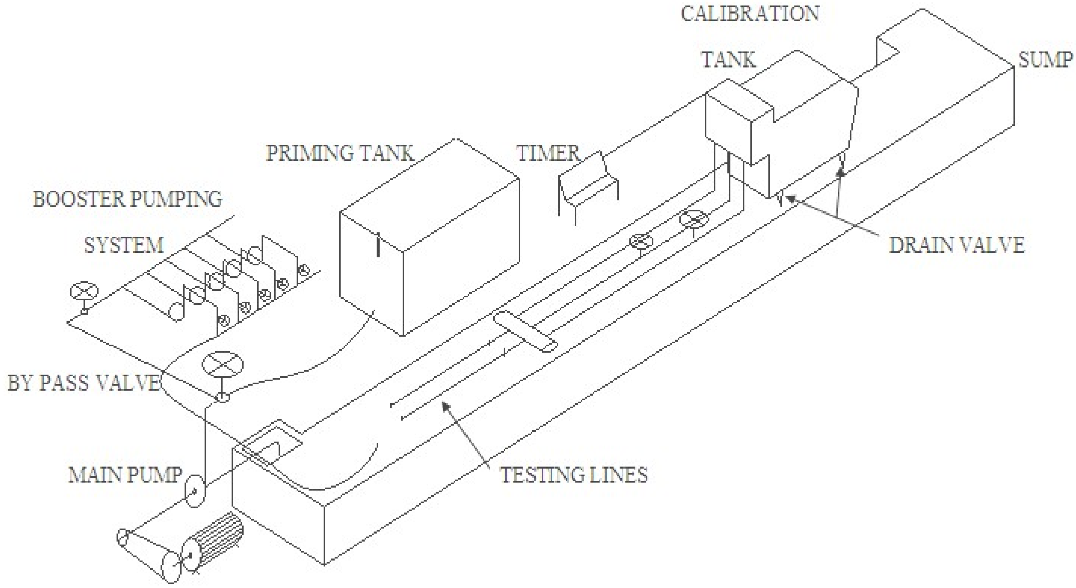


Figure 3.4: Schematic layout of Volumetric Calibration Standard

3.4.6 Advantages and Limitations

Advantages

- Direct traceability to SI units
- Simple and robust measurement principle
- Well suited for steady flows and moderate flow rates

Limitations

- Less suitable for very high flow rates (large tanks required)
- Slightly higher uncertainty than gravimetric method

3.4.7 Typical Applications

- Calibration of electromagnetic, ultrasonic, turbine, and mechanical water meters
- Laboratory reference calibration facilities
- Validation of secondary and field calibration systems

3.5 SUBMERSIBLE PUMP TESTING IN A VOLUMETRIC CALIBRATION FACILITY

The Division has over **three decades of experience** in testing and evaluation of rotodynamic and submersible pump sets. Hydraulic performance and overload tests have been conducted for multiple State Governments including Rajasthan, Bihar, Karnataka, and Uttar Pradesh. All tests are conducted in accordance with applicable standards. Electrical parameters are monitored using a Multifunction Load Manager, and pump efficiency and guarantee factor are evaluated to verify operation at design head and discharge.

3.5.1 Purpose of Submersible Pump Testing

Testing of submersible pumps is carried out to evaluate hydraulic performance, including discharge, head, efficiency, power consumption, and overall performance characteristics, under controlled conditions. IS 8034 specifies requirements for submersible pumpsets for clear water, while IS 9137 provides general guidelines for acceptance tests on rotodynamic pumps. When conducted in a volumetric calibration facility, pump discharge is measured using a primary volumetric method, ensuring high accuracy and direct traceability to SI units.

3.5.2 Principle of Volumetric Discharge Measurement

In a volumetric calibration facility, the discharge of the submersible pump is determined by measuring the volume of water collected in a calibrated volumetric tank over a known time interval. This method directly realizes discharge from volume and time, without dependence on a reference flow meter, making it suitable for type tests, performance verification, and acceptance testing as per BIS requirements.

The discharge is calculated as:

$$Q = \frac{V}{t}$$

Where:

- Q = discharge (m^3/s or L/s)
- V = collected volume (m^3 or L)
- t = collection time (s)

3.5.3 Test Facility Layout (Volumetric Method)

A typical submersible pump test setup consists of:

- Sump / Test Tank with adequate submergence
- Submersible Pump Under Test (PUT)
- Delivery Pipeline with flow control valve
- Pressure Gauge / Transducer at delivery side
- Non-return and isolating valves
- Diverter System
- Calibrated Volumetric Tank with level sensors
- Measuring Instruments:

- Pressure gauges (head measurement)
- Energy meter / power analyzer
- Tachometer (if required)
- Temperature sensors

The volumetric tank is calibrated against dimensional standards, ensuring traceability as per ISO/IEC 17025.

3.5.4 Test Conditions and Requirements (IS 8034 / IS 9137)

- Pump shall be tested with clean water at ambient temperature
- Adequate submergence shall be maintained to avoid vortex formation
- Air entrainment and leakage in delivery line shall be eliminated
- Pump shall operate at rated voltage and frequency
- Steady operating conditions shall be ensured before recording observations

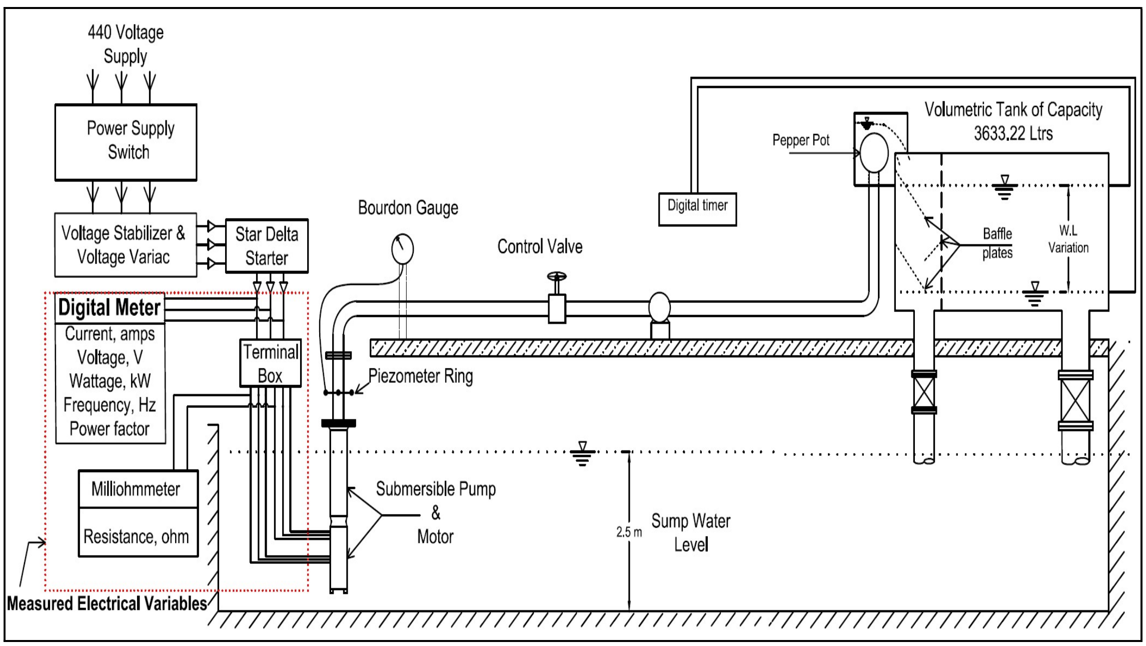


Figure 3.5: Schematic layout of Pump Test Facility

3.5.5 Parameters Measured During Testing

a) Discharge

Measured using the volumetric tank and timer as the primary reference method.

b) Total Head

Calculated as the difference between delivery head and suction head (for submersible pumps, suction head is usually negligible and measured as static water level). Corrections for velocity head may be applied as per IS 9137.

c) Input Power

Measured using a calibrated energy meter or power analyzer.

d) Efficiency

Overall efficiency is calculated as:

$$\eta = \frac{\rho g H Q}{P_{in}}$$

Where:

- H = total head (m)
- P_{in} = input power (W)

3.6 TEST PROCEDURE

The complete test set-up and the measurement system employed for the test pumpsets will be inspected by the engineers and each representative of the manufacturers before commencement of tests. Prior to testing of each pump, the test procedure and method of calculations were explained to representatives of the pump manufacturers and representatives of end user. It was accepted by all concerned that even though the tests are to be conducted according to IS-9137 which provides for class `C’ testing, the overall accuracy during the measurements was far better than what is stipulated in class `C’ standards, owing to precision measuring instruments developed for the tests.

Representatives of manufacturers were allowed to take some trial readings before the actual test. Subsequent to trial by pump manufacturer, actual tests were undertaken by CWPRS which were witnessed by officers and representative of concerned pump manufacturer.

3.6.1 Hydraulic Performance Tests

Before the commencement of the hydraulic performance tests, one-metre length of supply cable connected to the submersible motor was cut and its resistance was measured independently. The voltage stabilizer was set precisely to 415 volts initially; the pump under test was operated for one hour for allowing hydraulic conditions to stabilise. After idle running of the pump, head (H) on the digital pressure transducer/Bourdon tube pressure gauge, was set to a lower head value by throttling the valves on the delivery lines of the pump. After setting head within test range some time was allowed to stabilize the circuit. During measurement the discharge of the pump, the valves provided at the bottom of the volumetric tank were simultaneously closed. The time taken for water to fill up the volume of the tank between the two electrodes was observed on an electronic digital timer. At each test point various parameters were recorded when volumetric tank was filled about 50% of its volume. The procedure was repeated for various delivery head from minimum to maximum to cover the entire operating head range (-25% to +10%) of test. This was continued till the reading of the Bourdon gauge was above the maximum limit of operating range. The power loss in the mains cable up to the motor terminal was calculated for computing the corrected overall efficiency.

To ensure the motor is not overheated during entire range of head variation (to cover -25% to +10% of rated head) the winding current is recorded for each pump and compared with specified value in the name plate.

As required by IDUP, pump test results need to be conducted at the available frequency and to scale up the results to rated frequency i.e. 50 Hz using formulae given in IS-9137. Accordingly, the flow rate, head and power readings were scaled up. Guarantee factor was computed as per procedure indicated in IS-9137. The values of various hydraulic/ electrical parameters as observed for each pump were computed/ noted from test results and tabulated as per requirement of IDUP.

3.6.2 Under-voltage and Over-voltage Tests

During the under-voltage test on the motor of the test pump, voltage stabilizer was set to a value of 353 Volts i.e. 415 Volts - 15% and the digital pressure transducer was adjusted at the duty point head. As in case of the normal hydraulic performance tests, the readings of the input power, voltage, current, frequency, power factor, the time, etc., were observed and recorded.

This was followed by over-voltage test**.** During this test on the motor, the output voltage of the voltage stabilizer was set to a value of 456 Volts i.e. 415 Volts + 10 % and similar observations as stated above were recorded.

3.6.3 Overload Tests

For conducting overload tests, initially the value of the motor winding resistance i.e. cold resistance of each of the three phases of connecting cable and that of the motor windings were recorded using a digital milliohm meter. By throttling the valve on delivery pipe line of the pump, the value of input power to the motor was adjusted to power at duty point declared by the pump manufacturer. The value of power factor, current drawn by the motor at this set value of rated power was measured & recorded.

The pump will be then subjected to overload power (1.2 times the rated power) as indicated in tender by adjusting the valves on the delivery lines of the pump. In order to derive the corresponding value of overload input power to the motor, efficiency of motor as declared by the pump manufacturer was considered in accordance with the procedure agreed upon by and representative of pump manufacturers. The readings of the current, voltage, frequency, power were recorded. After one hour of operation of the pump with overload power, the motor was stopped and immediately the values of the winding resistance i.e. hot resistance of each of the phases were measured with high precision quick response digital Ohm-meter. The temperature rise of the windings was determined using the relationship given in the relevant IS on motor testing.

3.6.4 Test Points and Performance Curves

As per BIS standards, tests are conducted at multiple operating points to develop:

- Head vs Discharge (H–Q) curve
- Efficiency vs Discharge curve
- Power vs Discharge curve

These curves are used to verify compliance with guaranteed performance values.

3.7 ACCEPTANCE CRITERIA (INDICATIVE)

- Discharge and head shall meet specified tolerances
- Efficiency shall not fall below the guaranteed value beyond permissible limits
- Smooth operation without abnormal noise, vibration, or overheating

3.8 MEASUREMENT UNCERTAINTY & TRACEABILITY

- Discharge measurement uncertainty is governed by volumetric tank calibration, time measurement, and repeatability
- Head measurement uncertainty depends on pressure gauge accuracy and level measurement
- Power measurement uncertainty depends on electrical instrumentation

The volumetric method ensures direct traceability, making the facility suitable for NABL-accredited pump testing laboratories.

3.9 APPLICATIONS

- Type testing of submersible pumps
- Acceptance testing for procurement
- Performance verification for irrigation, water supply, and industrial pumps
- R&D and comparative performance studies

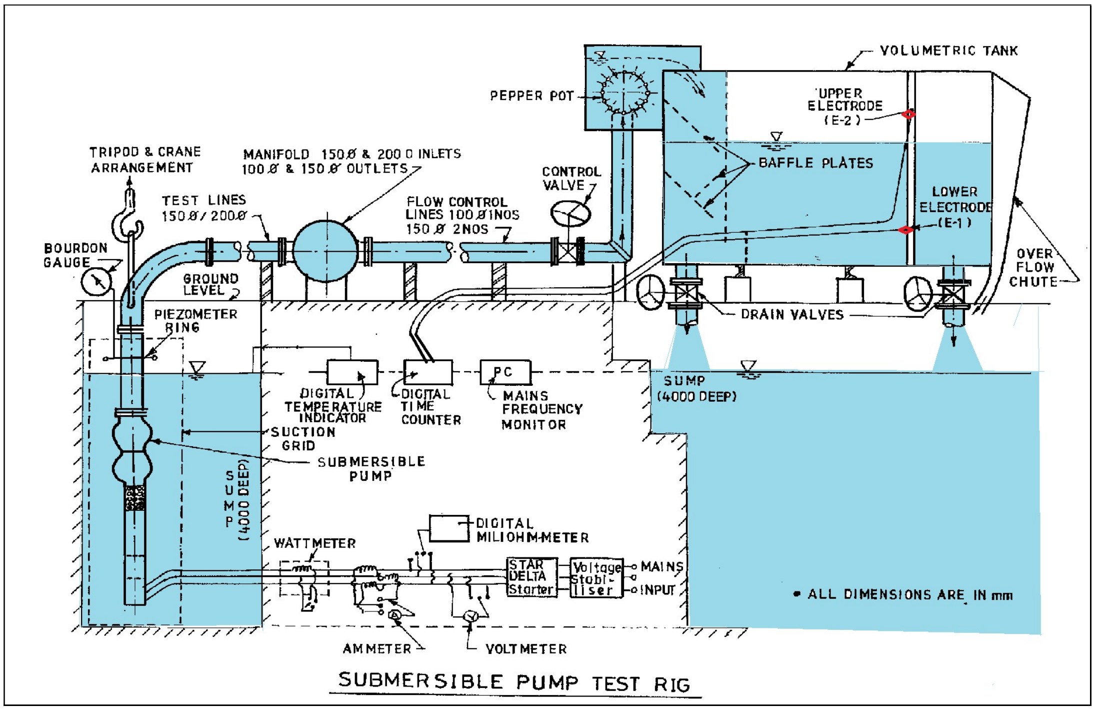


Figure 3.6: Major Components of the Pump Test Rig

Typical Studies Carried in Calibration & Testing Facility in HMCI Division

- Calibration of large size flowmeters at very high flowrate for Gujarat Water Infrastructure Limited, Odisha Irrigation Department, Public Health Department Rajasthan,Vidharbh Irrigation Development Corporation, Narmada Gambhir Water Supply Project for Madhya Pradesh Jal Nigam Maryadit , CIDCO of Maharashtra, Maharashtra Industrial Development Corporation, Vijayawada Municipal Corporation, Vizag Municipal Corporation, Water Supply Scheme Firozabad, Utter Pradesh Through State Water and Sanitation Mission etc.
- Testing industrial filters for Bharat Heavy Electricals Limited for thermal power projects like IEL, Jamshedpur (Tata Power), National Thermal Power Corporation, Garden Reach Shipbuilders and Engineers Limited for survey vessel, Chenab Valley Power Projects Limited etc.
- Testing of various types of valves for Maharashtra Jeevan Pradhikaran, Koso Valves, IMICCI for project of Qatar Energy, Forbes Marshal for project of ISRO etc.
- Performance evaluation of submersible pumps for irrigation department of Uttar Pradesh, Rajasthan etc.

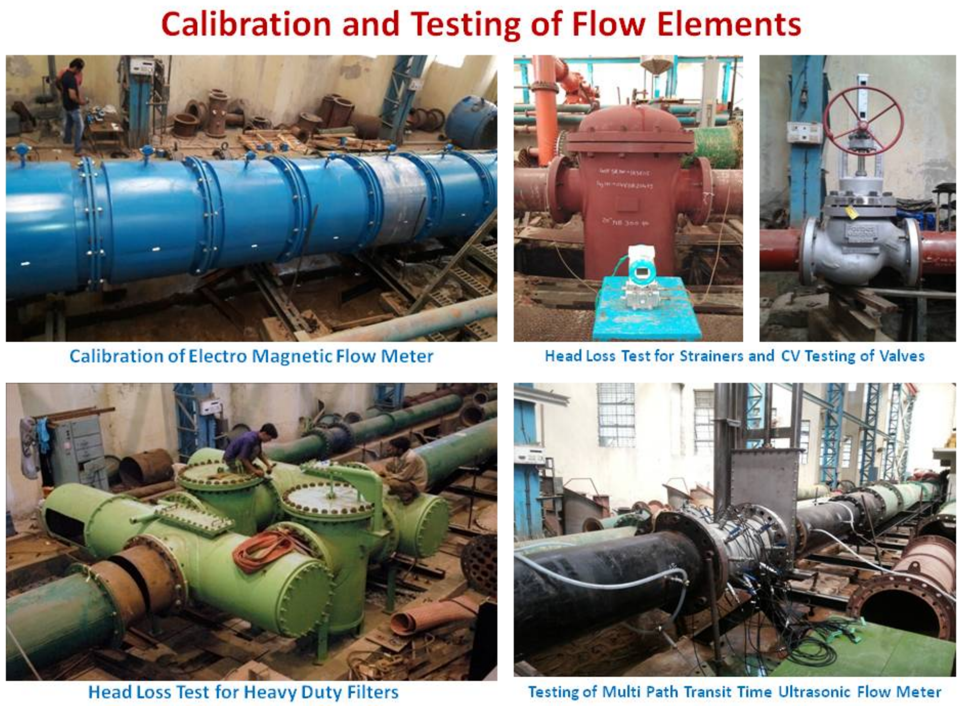


Figure 3.7: Calibration and Testing of Flow Elements

Figure 3.8: Submersible Pump Testing

CHAPTER 4
FLOWMETER TYPES AND APPLICATIONS

Measurement of water flow in closed pipes is essential for hydraulic engineering applications such as water supply systems, irrigation networks, pump testing, hydropower stations, industrial processes, and calibration laboratories. Flow meters installed in closed conduits measure the rate of flow without exposing the fluid to the atmosphere, ensuring accuracy, safety, and operational continuity.

4.1 CLASSIFICATION OF FLOWMETERS FOR CLOSED PIPES

Broadly two types of flow meters are widely used in industries:

- Volumetric Flowmeters and
- Mass Flowmeters

4.1.1 Volumetric Flowmeters

Volumetric flow meters got their name because these flow meters measure the fluid volume passing through a specific location in a set period of time. Volumetric flow meters provide an instantaneous analog, digital, or pulse output of the volumetric flow rate of the liquid or gas. Various types of Volumetric Flowmeters are available as listed below

- Differential Head type
    - Orifice plates
    - Venturi meters
    - Annubar
- Differential Area type (Rotameters)
- Electromagnetic flowmeters
- Ultrasonic flowmeters
- Turbine flowmeters
- Vortex flowmeters
- Positive Displacement Meters

4.1.2 Mass Flowmeters

Mass flow meters measure the fluid mass flow rate that travels through a tube per unit of time. There are two types of mass flowmeters as mentioned below

- Coriolis mass flowmeter and
- Thermal mass Flowmeters

4.2 DIFFERENTIAL HEAD TYPE FLOW METERS

4.2.1 Orifice Plates

Orifice plates are differential pressure type flow meters that measure flow by introducing a thin, sharp-edged plate with a central opening into the pipeline, causing a pressure drop proportional to the square of the flow velocity. The flow rate is determined by measuring the differential pressure between upstream and downstream pressure taps using Bernoulli's principle. Orifice meters are widely used for water measurement due to their simplicity, low initial cost, and ease of installation, although they incur significant permanent head loss and require straight pipe lengths for accurate measurement.

4.2.2 Venturi Meters

Venturi meters operate on the differential pressure principle by accelerating water through a smoothly converging section, a throat, and a gradually diverging section, resulting in a measurable pressure difference between the inlet and throat. The gradual geometry minimizes energy losses, making venturi meters highly accurate and efficient for measuring water flow in large diameter closed conduits. They are commonly used in water supply systems, irrigation pipelines, and hydropower installations where head loss must be minimized, though their high cost and bulky construction are notable limitations.

4.2.3 Annubar (Averaging Pitot Tube)

Annubar flow meters measure flow by sensing the average differential pressure across multiple pressure ports located along a probe inserted into the pipeline. The pressure difference between the stagnation pressure and static pressure is proportional to the flow velocity. Annubars offer lower pressure loss compared to orifice plates and are suitable for large pipes carrying water, making them popular in industrial water systems and retrofit installations where cutting the pipe is undesirable.

4.2.4 Rotameters

Rotameters are variable area flow meters (differential area type) in which water flows upward through a vertically mounted tapered tube, causing a float to rise until the drag force balances the weight of the float. The vertical position of the float directly indicates the flow rate. Rotameters are simple, reliable, and widely used for low-flow water applications, laboratory experiments, and auxiliary water lines; however, they are limited to vertical installation and moderate pressure and temperature conditions.

4.3 ELECTROMAGNETIC FLOWMETERS

Electromagnetic flow meters measure water flow based on Faraday's law of electromagnetic induction, where a voltage is induced when conductive water flows through a magnetic field generated perpendicular to the flow direction. The induced voltage is directly proportional to the flow velocity, enabling accurate volumetric flow measurement. These meters are highly suitable for clean water, wastewater, and slurry flows, as they have no moving parts and cause negligible head loss, making them ideal for water supply networks and calibration facilities.

4.4 ULTRASONIC FLOWMETERS

Ultrasonic flow meters measure flow using high-frequency sound waves transmitted through water, either by transit-time or Doppler principles. In transit-time meters, the difference in travel time of ultrasonic pulses moving with and against the flow is used to calculate flow velocity, while Doppler meters rely on frequency shifts caused by suspended particles or bubbles. Ultrasonic meters are non-intrusive, cause no pressure loss, and are especially suitable for large diameter water pipelines and temporary flow measurement applications.

4.5 TURBINE FLOWMETERS

Turbine flow meters measure water flow by converting the kinetic energy of the flowing fluid into rotational motion of a turbine rotor placed in the pipeline. The rotational speed of the turbine is proportional to the flow velocity and is sensed electronically to determine the flow rate. These meters provide good accuracy over a wide flow range and are commonly used for clean water applications, pump testing, and industrial water measurement, though their performance can degrade in the presence of suspended solids.

4.6 VORTEX FLOWMETERS

Vortex flow meters operate on the principle of vortex shedding, where vortices are alternately formed downstream of a bluff body placed in the flow path. The frequency of vortex formation is directly proportional to the flow velocity and is detected using pressure or piezoelectric sensors. Vortex meters are robust and suitable for water, steam, and industrial fluids, offering good accuracy with relatively low maintenance, though they require sufficient flow velocity to generate stable vortices.

4.7 POSITIVE DISPLACEMENT METERS

Positive displacement flow meters measure water flow by trapping and counting discrete, fixed volumes of fluid passing through the meter using mechanical elements such as pistons, gears, or rotors. The total flow is obtained by summing the number of displaced volumes over time. These meters provide very high accuracy, particularly at low flow rates, and are widely used in domestic water supply and laboratory measurements; however, they are sensitive to wear and are generally unsuitable for large pipelines or dirty water.

4.8 CORIOLIS MASS FLOWMETERS

Coriolis mass flow meters measure flow directly by utilizing the Coriolis effect, where a force is generated when a fluid flows through vibrating tubes. As water passes through the oscillating tubes, a phase shift or deformation occurs that is proportional to the mass flow rate. Sensors detect this change and convert it into an accurate mass flow measurement, independent of fluid density, temperature, or pressure variations. Coriolis flow meters offer very high accuracy and repeatability and are widely used in laboratory calibration systems and high-precision industrial applications, although their high cost and limitation to smaller pipe diameters restrict their use in large water pipelines.

4.9 THERMAL MASS FLOWMETERS

Thermal mass flow meters operate on the principle of heat transfer, where the rate of heat loss from a heated sensor placed in the flow stream is directly related to the mass flow rate of the fluid. As water flows past the heated element, it carries away heat, and the temperature difference between the heated and reference sensors is used to determine the mass flow. Thermal mass flow meters provide direct mass flow measurement and are suitable for low-velocity and low-flow applications; however, their use in water systems is limited compared to gases due to water's high thermal conductivity and sensitivity to fluid temperature variations.

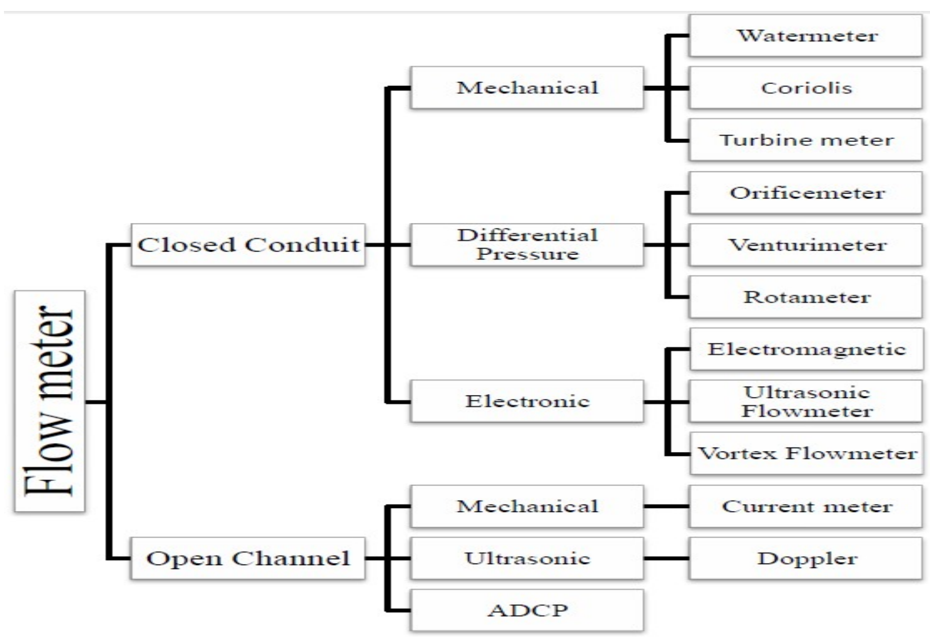


Figure 4.1: Types of Flow Meters

CHAPTER 5

FLOW MEASUREMENT AT SITE – ISSUES AND CHALLENGES

Flow measurement plays a major role in the effective utilization water resources. Hydraulic Machinery & Cavitation Division of CWPRS performs testing and calibration of closed conduit flow measurement instruments and also undertakes field studies for assessing hydro turbine performance, performance evaluation of pump intakes and secondary calibration of flow meters installed at various sites. The main objective of major studies are aimed to enhance the flow metering capacity to handle various demands from Central and State Government agencies, Municipal Corporations that caters water for power development, irrigational purposes & drinking water supply schemes respectively and also will significantly contribute to the benefit of various small scale industries and stakeholders involved in custody transfer and flow measurement, thereby contributing to sustained and effective utilisation of water resources.

This technical memorandum describes and tries to find out the underlying issues in the measurement of fluid flow and the challenges in incorporating the right flow meter at the required site location.

5.1 FLOW MEASUREMENT AT SITE

While different approaches have been adopted to estimate or quantify the flow, there are some common issues which arise during and after the installation of flow meters. Also site calibration of flow meters becomes a challenge in measuring the flow rate with minimal uncertainty due to site constraints. The basic framework revolves around the choice of appropriate flow meter to be selected and included the periodic calibration for its reliable data with acceptable accuracy through-out its lifetime.

Installation effect is one of the major parts in contribution to the accuracy of every flow measuring process. A flow meter will only perform to its maximum efficacy if it is installed correctly. The flow meters probability of living up to the manufacturer's accuracy and uncertainty claims increases if little consideration is given during the installation process, the effects can be large or small but can be dramatically reduced if properly installed. The following sub topics describe some of the issues and challenges faced during the site calibration and inspection. It is important for anyone involved in flow measurement from engineers, to managers, to sales people, to customers.

5.2 FLOW PROFILES

A velocity profile describes how fast a fluid is flowing at different points across the pipe. If there was no friction at all, the fluid would all move at the same velocity like a solid.

However, the pipe wall creates friction and a thin layer of fluid next to the pipe wall does not move. The further away from the pipe wall the fluid is, the less friction there is and so the fluid moves at increasingly higher velocities. This means that the highest velocity occurs at the centre of the pipe i.e. at the furthest point from the pipe walls. How the velocity profile changes across the pipe depends on the nature of the flow regime; laminar or turbulent.

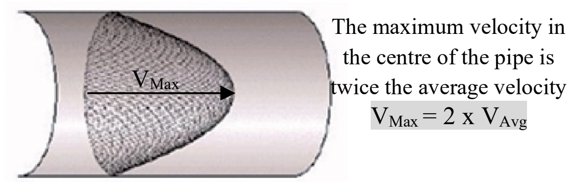


Figure 5.1 Velocity Profile of Laminar Flow

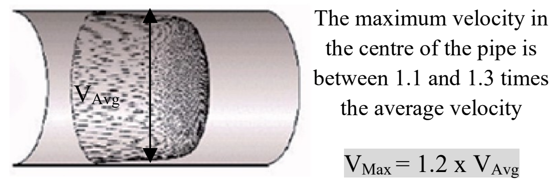


Figure 5.2 Velocity Profile of Turbulent Flow

Velocity profiles differ in various shapes with respect to the piping profile like bends, slopes, converging diverging sections, bifurcations etc. These phenomena calls for a required straight run to the upstream and downstream of the flow meter for accurate flow measurement.

5.3 SITE REQUIREMENTS FOR SPECIFIC FLOW METERS

Flow meters are designed for use in ideal conditions but in reality, they need to cope with slopes, valves and bends distorting the flow, vibrations, electromagnetic noise, acoustic noise, particles and bubbles, to name but a few and all of them are potential sources of error. There are many different types of flow meter and installation effects will influence them in different ways. For example, some can have large errors caused by swirl whereas some will be relatively unaffected by it.

Standards and manufacturers quote the minimum length of straight pipe required, but many constraints raise during the erection of a piping system. The following topics discuss some of the site constraints related to specific flow measuring instruments.

5.4 TURBINE FLOW METERS

Turbine meters are used successfully and widely in both liquid and gas measurement. They are made differently for gas and liquid measurement because of the difference in driving forces of the fluids and internal bearing frictions. However, the basic operation is the same for gas or liquid service. The turbine meter is a velocity measuring device and provides volume. Most of all the flow metering devices requires 10 times diameter at the upstream and 5 times diameter at the downstream side as shown in Figure 5.3.

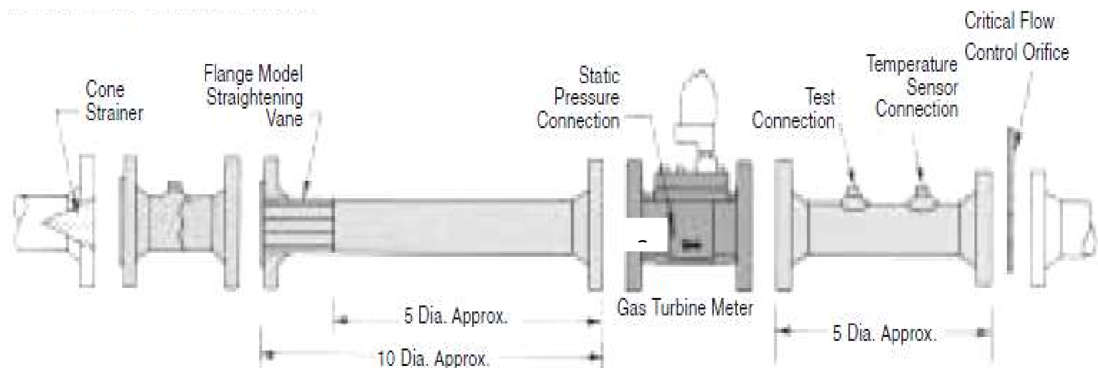


Figure 5.3 Required upstream and downstream pipe run

Figure 5.4 Water meter installed after series of flow elements

Figure 5.5 Water meter installed after reducer

Figure 5.6 Water meter installed at right location

Maintenance for properly operated turbines consists of periodic cleaning and physical inspection. Calibrations may be required to reconfirm proof curves on custody transfer meters. This may be by calibration against standardized master meters or direct calibration against standards. Require upstream flow pattern to be non-swirling, which necessitates straightening vanes.

5.5 VORTEX SHEDDING METERS

The vortex shedding meter has come into prominence and usage in the last 20 years for both gas and liquid measurement. It has received acceptance in the industrial flow measurement area and, to a limited degree, the custody transfer measurement area. The vortex shedding meter operates on the Von Karman effect of flow across a bluff body. This principle states that flow will alternately shed vortices from one side and then the other of a bluff body, and the frequency of shedding is proportional to velocity across the body. When this velocity is combined with the hydraulic area of flow in a stream, the rate of flow can be established.

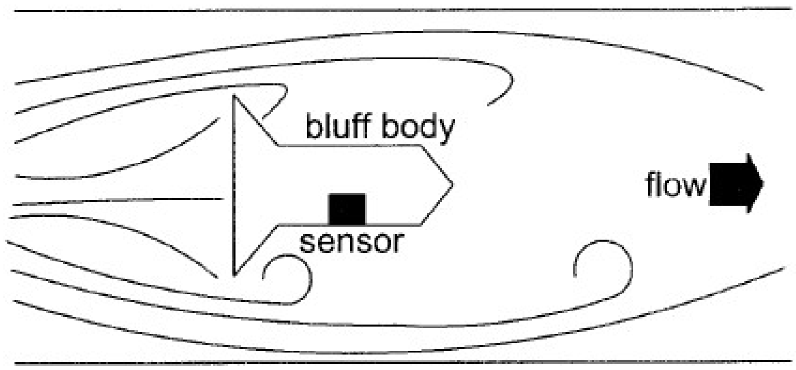


Figure 5.7 Major components in a vortex-shedding meter

Since the meter reacts to velocity, it follows that a proper flow pattern must be presented to the bluff body. This is accomplished by using straightening vanes, flow profile generators, and/or straight upstream piping to eliminate swirl distorted patterns. Installation requirements are similar to other velocity sensitive meters.

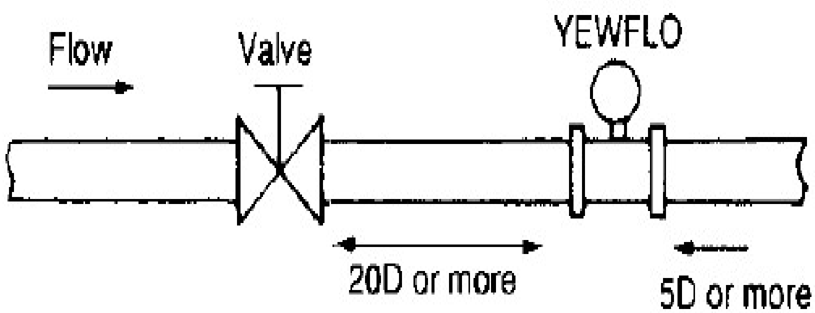


Figure 5.8 Required upstream length for vortex meter after valve as per standard

Figure 5.9 Flow meter installed at a location subjected to vibrations and insufficient upstream length

5.6 ULTRASONIC METERS

The ultrasonic meter category contains a number of different designs for measuring an average velocity in a flowing system. They are all based on an ultrasonic signal being changed by or reflected from the flowing stream velocity. Meter accuracy relates to the ability of the system to represent the average velocity over the whole stream passing through the meter body's hydraulic area. This ability affects installation requirements and accuracy of results obtained.

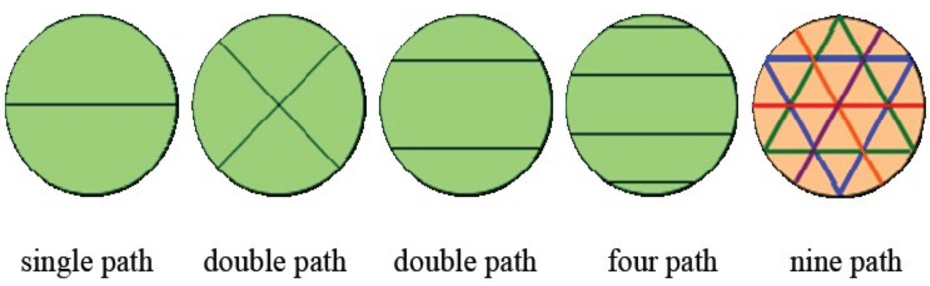


Figure 5.10 Different types of Transit-time ultrasonic meter for average flow measurement

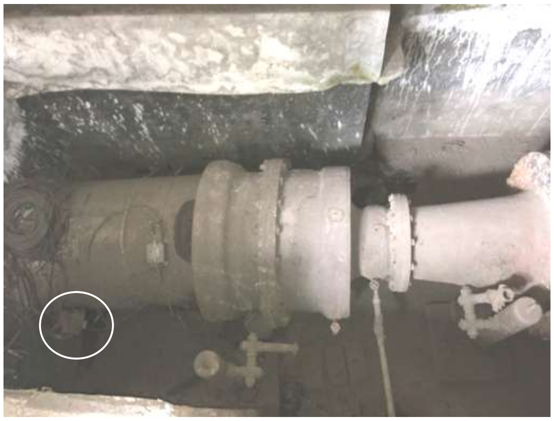


Figure 5.11 USFM installed at wrong location
(without replacing the old venturi meter with a straight length pipe)

Figure 5.12 Poorly maintained clamp on type USFM (also no periodic calibration done)

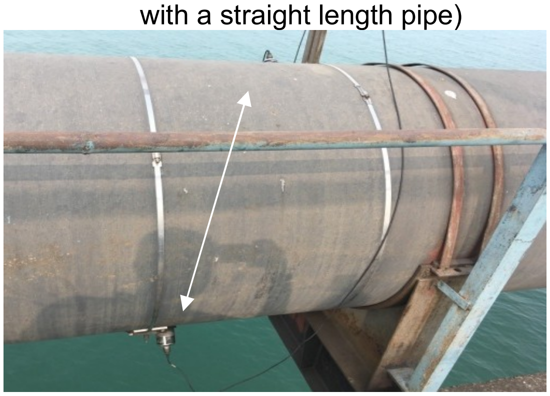


Figure 5.13 Clamp on type direct type USFM

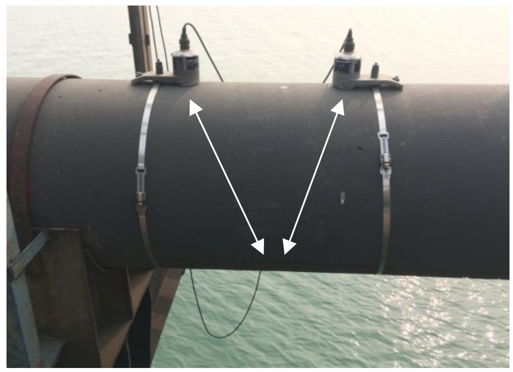


Figure 5.14 Clamp on type V-method USFM

Continuous power supply is required for uninterrupted operation. For a single path or reflection unit, flow profile must be fully developed for an average velocity to be determined but use of a multiple-path ultrasonic flow meter for average disturbed flow patterns including small swirls minimizes the flow profile problems. Most recommendations call for fluid Reynolds numbers less than 4,000 (laminar flow) or above 10,000 (turbulent flow). Nonlinearities in the transition region between these two Reynolds numbers degrade meter accuracies. The ultrasonic flowmeters should be installed upstream of flow obstacles, such as elbows, reducers, or valves. Ensure that the longest possible straight pipe is between the obstacle and the meter. The length of straight pipe can be reduced to five pipe diameters if an additional error of 1 percent maximum is acceptable.

Paying attention to these recommendations for flowmeter installations will help ensure successful applications with good accuracies.

5.7 ELECTROMAGNETIC FLOW METER

Magnetic meters are relatively insensitive to errors caused by nonsymmetrical velocity patterns or swirl. The general rule of thumb for straight piping is a five-diameter length of piping upstream and three diameters downstream from the meter (measured from the center of the tube). However, this type of meter generally requires over 10 diameters of straight pipe upstream for its installation and there can be problems with large bore meters. On the plus side, electromagnetic meters are not as affected by swirl as much as other types of meters are.

Particles or bubbles present in a fluid can affect an electromagnetic flow meter as they tend to either rise to the top of the pipe or fall to the bottom. One way to reduce the effect would be to install the electrodes horizontally on the pipe wall.

Figure 5.15 Electromagnetic Flowmeter installed at delivery line

Figure 5.16 Electromagnetic Flowmeter installed at a flow measuring chamber

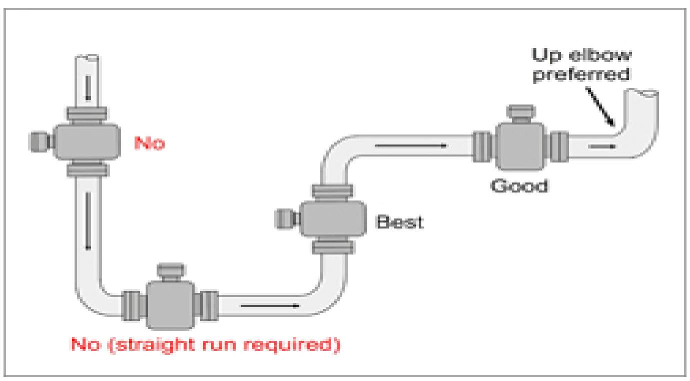


Figure 5.17: When installing magnetic meters, avoid downward flows. Horizontal configurations following an elbow require at least five pipe diameters of straight pipe upstream from the meter

5.8 DIFFERENTIAL-PRESSURE FLOW METERS

DP flowmeters measure the drop in pressure across a flow element in the piping, such as an orifice plate. The measured flowrate is a function of the pressure drop. Professional organizations provide installation guidelines for DP flowmeter installations. These guidelines help to minimize disturbances to the fluid-velocity profile.

Straight-pipe runs upstream and downstream from the DP flow element help to guarantee a fully developed fluid-velocity profile that permits a predictable pressure drop. For an orifice, the length of straight run required depends on both the beta ratio of the installation and on the nature of the upstream components in the pipeline. (Beta ratio is the diameter of the orifice divided by the pipe diameter) Corrosion, erosion and dirt can also lead to errors in differential pressure meters as they can cause the orifice or throat diameter to increase or decrease.

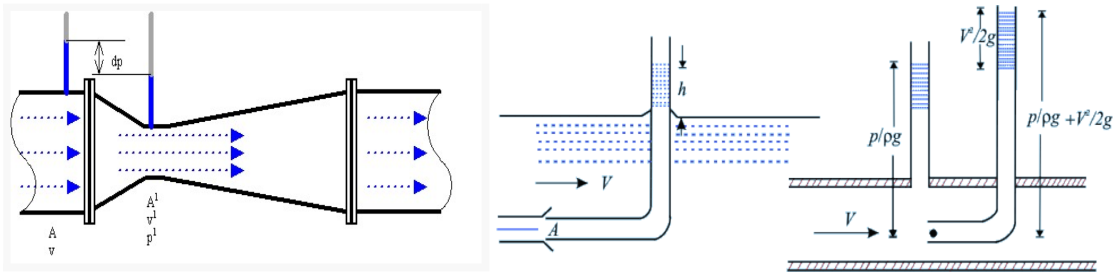


Figure 5.18 DP type flow meter principles (left venturi meter and right pitot tube meter)

Figure 5.19 Venturi type DP flow meter

Figure 5.20 Pitot tube DP transmitter

✓ Installation of the right flow meter at right place can be performed based on the following Standards in order to make accurate flow measurements and to perform periodic secondary calibration for uninterrupted flow measurement process.

The ISO standards for meter installations are a good starting point:

- Differential pressure – ISO 5167
- Electromagnetic – ISO 6817
- Ultrasonic – ISO 6416
- Turbine – ISO 2715
- Variable area – ISO 11605
- Coriolis – ISO 10790
- Positive displacement – ISO 2714
- Critical nozzles – ISO 9300
- Thermal mass – ISO 14511

Typical Studies Carried for various Sites

❖ Head loss measurement in the Water Conductor System of Bairasiul Power Station, Chamba for NHPC (2023). Computed the head loss for different plant loads under various combination of turbines in operation and projected the discharge vs head loss curve with respect to the plant load.

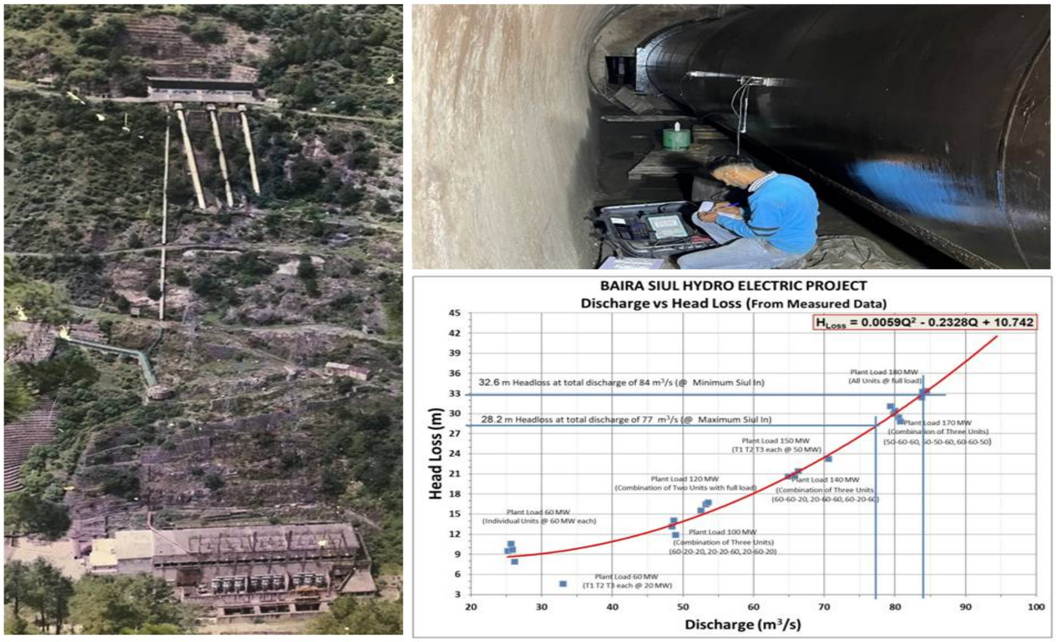


Figure 5.21: Head Loss Measurement in Water Conductor System of Baira siul Power Station

❖ Performance evaluation of Salal Hydro Electric Project, J & K for NHPC after RMU works (2021). The performance test was conducted for the turbine Unit-6 (with replaced runner) and the technical report submitted to project authorities following the Renovation and Upgradation, undertaken for the project.

Figure 5.22: Performance evaluation of Salal Hydro Electric Project, J & K for NHPC

❖ On-Site Calibration of Flowmeters at Ajmer, Rajasthan for M/S NS Instruments and Controls, New Delhi. The objective of this study was to calibrate 3 nos. flow meters at three pumping stations (Bisalpur, Thadoli, and Kekri) of Public Health Engineering Department (PHED), Ajmer Region, Rajasthan, to ensure accurate flow measurement. It is recommended to install flow meters with straight lengths of minimum 10D upstream and 5D downstream and avoid installing flow meters near flow-disturbing elements like valves and gates. Also it is recommended to calibrate flow meters in a laboratory before commissioning or after repair/maintenance and Upgrade existing layout and piping to ensure standard flow measurement practices.

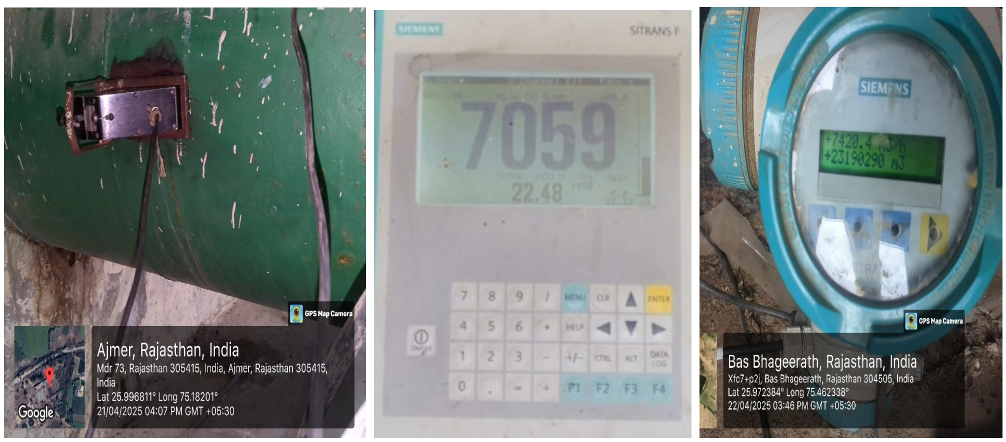


Figure 5.24: On-Site Calibration of Flowmeters at Ajmer, Rajasthan

❖ Efficiency evaluation for all the four Francis turbines of Koyna Stage IV units were carryied out at 652.75 m KRL and 643.4 m KRL at site. From the data recorded it is observed that turbines are operating at net head of 512 m, when the KRL value is around 652.75 m and 502 m, when the KRL value is around 643.4 m. At designed load of 250 MW the maximum efficiency (ηmax) was observed for the range of discharge from 55 m^3/s-56 m^3/s for all units under reservoir level between 652.75 m KRL to 643 m KRL. Hence it is better to keep this range for best performance.

Figure 5.24: On-Site Efficiency evaluation for Francis turbines of Koyna Stage IV

CHAPTER 6

INSTALLATION EFFECTS OF A CLAMP- ON TRANSIT TIME ULTRASONIC FLOW METER

The measurement of flow rates through large size pipelines is very significant for effective utilization of available resources. There is always a need to improve the measurement uncertainties, as it assumes greater importance when fluid is supplied on chargeable basis. Flow measurement is typical in various sectors such as lift irrigation, city water supply, cooling water for thermal and atomic power stations, inter-basin transfer of water, pump storage plants and inter-state water distribution. Measurement of high flow rates through penstocks of hydropower plants is also important for assessing efficiency of turbine units vis-a-vis optimum water utilization.

The stipulated accuracy of flow meters is only achievable if uniform velocity distribution at flow measuring section exists. However, the presence of flow disturbing elements like valve, bends, change in pipe cross sections, etc., in piping systems leads to asymmetric velocity distribution just downstream of these elements. To re-achieve the uniform velocity distribution at flow measuring section, downstream of above pipe specials, distorting the velocity distribution, it is essential to provide minimum requirement of straight lengths of pipe upstream and downstream of flow meter as recommended by standards. The value of this straight length (defined in terms of diameter – D of the pipe) depends upon the type of upstream disturbances.

Many a time, the site constraints do not permit to provide the adequate upstream and downstream straight lengths recommended by these standards leading to errors in flow measurement. However, the present BIS, ISO / IEC standards do not indicate the extent of deviation of measured flow rate from its true value when the recommended upstream straight lengths are not met. Thus, installation effects are considered as one of the most serious origin of errors in flow measurements.

All commonly used flow meter types are also affected to different extent due to condition of installation in terms of upstream straight length. Hence the accuracy of flow measurement of ultrasonic flow meters is also affected by different flow disturbances.

This technical memorandum addresses the effect of various undesirable piping configurations upstream of clamp on ultrasonic flow meter installed at various distances (viz. 1D to 12D) with various combinations of elbows and also with different diameters of pipes for various flow rates.

6.1 RESEARCH STUDIES

The effects of presence of flow distorting elements on uncertainty in flow measurement by clamp on type Ultrasonic Flow meter were established by conducting experiments with various piping configurations at the upstream of the flow meter e.g. single 90^0 elbow, double 90^0 elbows. The Fig. 7.1 shows the experimental setup for different locations of flow meter (1D to 12D) downstream of double elbows in plane for assessment of installation effects on flow measurement accuracy.

The detail of instruments used and their accuracy is as follows:

Flow meter : Controlotron 1010, Ultrasonic Clamp on type, Single path
Flow Rate : ± 0.3 % by volumetric method
Time : 0.001 second with digital timer
Flow stability : 0.001 % of set flow rate

Figure 6.1: Upstream double elbow in same plane

Experiments were repeated with triple 90^0 elbows out of plane at various upstream distances from flow meter (Figure 6.2).

Figure 6.2: Upstream triple elbow out of plane

The sensors of the ultrasonic flow meter were installed on pipe in 'V' traverse of ultrasonic beam i.e. with reflect mode (Figure.6.3).

Figure 6.3: Ultrasonic flow meter sensor mounting

These experiments were also repeated with different diameter of piping (150mm, 100mm & 80 mm NB) with same configuration of upstream elements. The percentage errors in flow measurement with respect to true flow indicated volumetrically are observed in flow range between 125 m^3/hr to 350 m^3/hr. The results of error in flow measurement owing to undesirable upstream straight lengths were also compared with improvised uncertainty in flow measurement when upstream straight length was maintained exactly as per Standards.

6.2 RESULTS AND DISCUSSIONS

Exhaustive experiments conducted with different piping configurations upstream of ultrasonic flow meter and associated extent of errors in the flow measurement on different diameters (150 mm NB, 100 mm NB and 80 mm NB) with varying flow rate at different locations and flow distortion configurations are indicated in Table 6.1-6.3

Table 6.1: % Error in flow rate on 150 mm NB pipe

Flow Velocity m/s	Minimum & Maximum % Error			
	Location of transducer on pipe of diameter (D)			
	1D to 3D	4D to 6D	7D to 9D	10D to 12D
Single Elbow				
2-4	-3.28 to -5.32	-2.85 to -3.40	-1.88 to -2.79	-0.80 to -1.50

4-6	-2.82 to -4.49	-2.00 to -3.05	-1.28 to - 2.22	-0.33 to -1.02
Double Elbow in same plane				
2-4	-4.12 to -5.09	-2.40 to -3.70	-1.39 to -2.99	-0.70 to -1.39
4-6	-3.64 to -4.80	-1.90 to -3.90	-0.87 to -2.60	-0.23to -1.12
Triple Elbow out of plane				
2-4	-4.21to -5.86	-3.00 to -4.20	-1.50 to -3.01	-0.78 to -1.80
4-6	-4.01to -6.12	-2.92 to -4.20	-1.32 to -2.80	-0.29 to -1.86

Table 6.2: % Error in flow rate on 100 mm NB pipe

Flow Velocity m/s	Minimum & Maximum % Error		
	Location of transducer on pipe of diameter (D)		
	1D to 3D	4D to 6D	7D to 12D
Single Elbow			
4-6	-3.11 to -5.32	-2.55 to -3.11	-1.50 to -2.48
6-8	-2.60 to -4.20	-1.70 to -2.70	-0.98 to -1.90
Double Elbow in plane			
4-6	-3.20 to -4.80	-1.55 to -3.05	-0.48 to -2.12
6-8	-2.30 to -4.50	-1.70 to -2.59	-0.09 to -1.98
8-10	-2.10 to -3.20	-1.20 to -2.02	-0.13 to -0.96
Triple Elbow out of plane			
4-6	-3.80 to -5.60	-3.40 to -3.80	-1.30 to -

			3.10
6-8	-3.33 to -5.05	-2.70 to -3.40	-0.90 to -2.90
8-10	-3.10 to -4.20	-2.20 to -3.02	-0.86 to -1.96

Table 6.3: % Error in flow rate on 80 mm NB pipe

Flow Velocity m/s	Minimum & Maximum % Error		
	Location of transducer on pipe of diameter (D)		
	1D to 3D	4D to 6D	7D to 10D
Double Elbow in plane			
5-7	-2.36 to -4.32	-1.20 to -1.98	-0.25 to -1.32
6-9	-1.82 to -3.55	-1.99 to -2.54	-0.57 to -1.64

The above tables indicate that for a same pipe diameter as upstream straight length increases, the extent of % error is reduced. It is also observed that as flow increases errors goes on decreasing, so maximum errors are observed in the low flow rates. The extent of error in flow measurement varies from -2 to -6 percentages and more owing to its installation with upstream straight length less than the recommended by the international standards.

The flow meter installed downstream of single elbow between 1D to 12D with flow velocity in the range 4 to 6 m/s leads to errors in flow measurement which gets reduced from -4.5% to -0.70% as the upstream straight length increases in respect of flow measurement on 150 mm NB pipe.

Flow measurement on 100 mm NB& 80 mm NB pipes with above configuration indicated that with flow velocity in the range 4 to 6 m/s leads to errors in flow measurement which gets reduced from -5.4% to -0.98% as the upstream straight length increases.

The experiments with double elbow in plane upstream of flow meter indicated that the extent of uncertainty in flow measurement are slightly less as compared with the experiments with single elbow and are in the range of -0.13% to -5.09% for the flow velocity of 2m/s to 10 m/s at various locations for pipe diameters 100mm NB and 150 mm NB

The following graphs show respective errors with different flow rates for the various flow distortions.

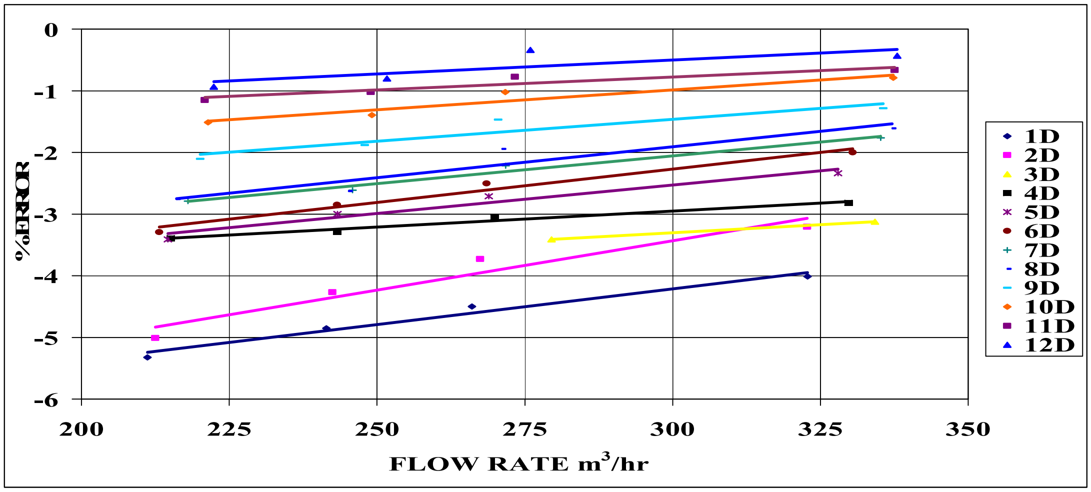


Figure 6.4: 150 mm NB single elbow in plane

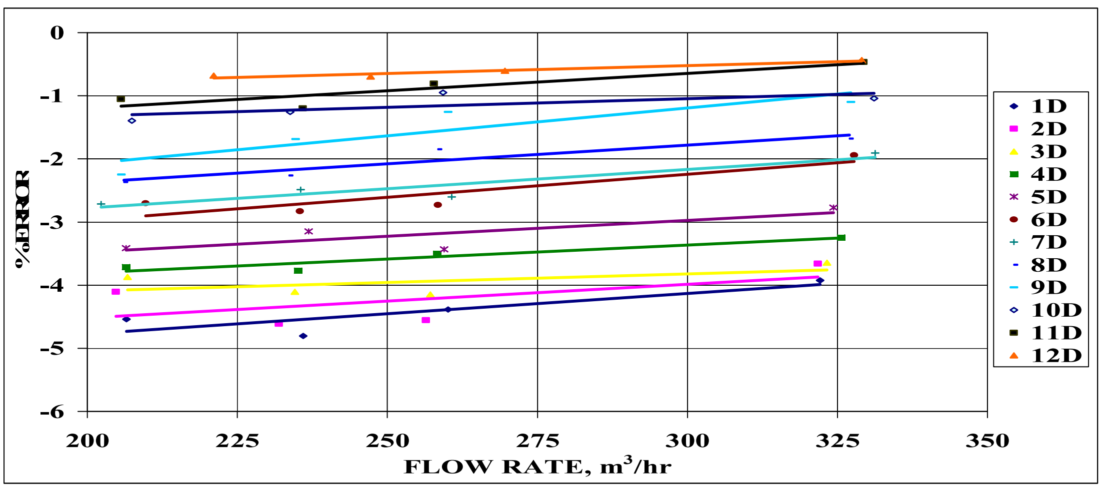


Figure 6.5: 150 mm NB double elbow in plane

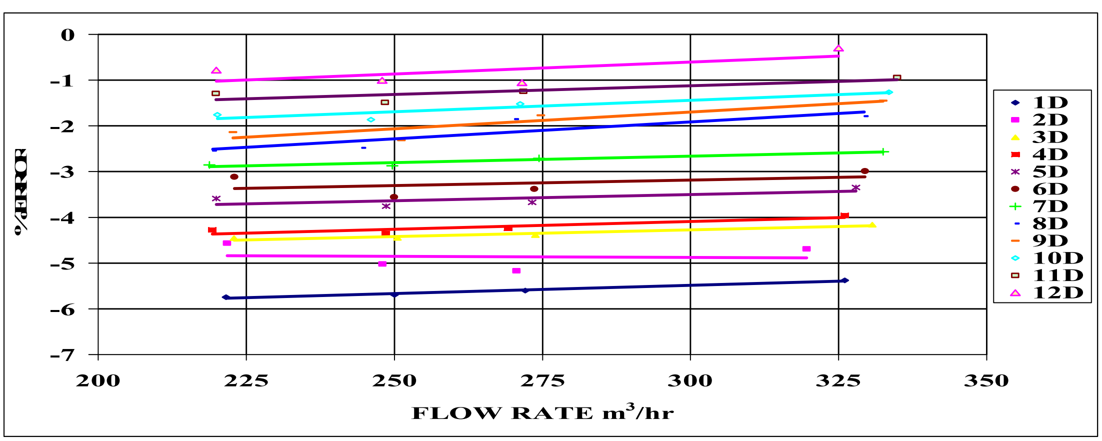


Figure 6.6: 150 mm NB triple elbow out of plane

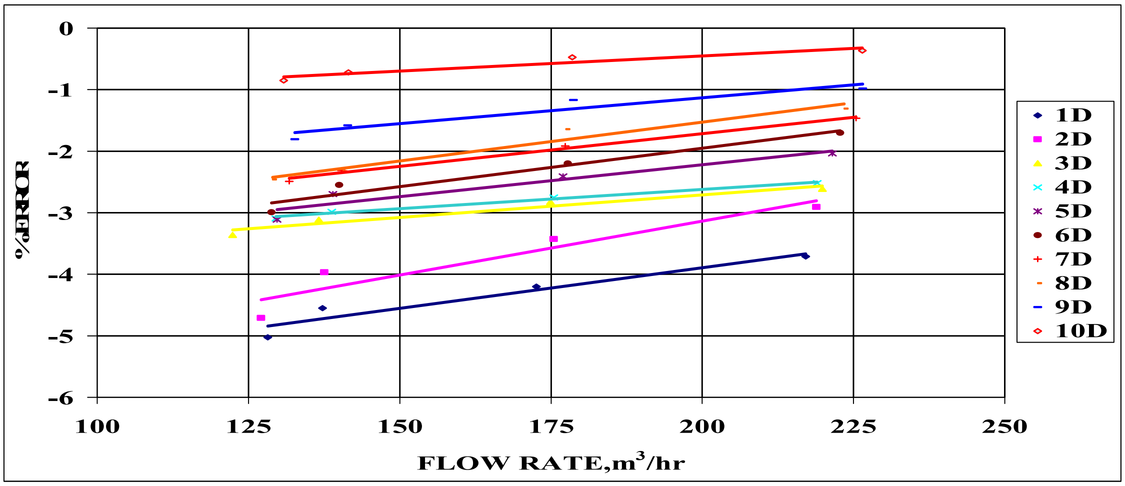


Figure 6.7: 100 mm NB single elbow in plane

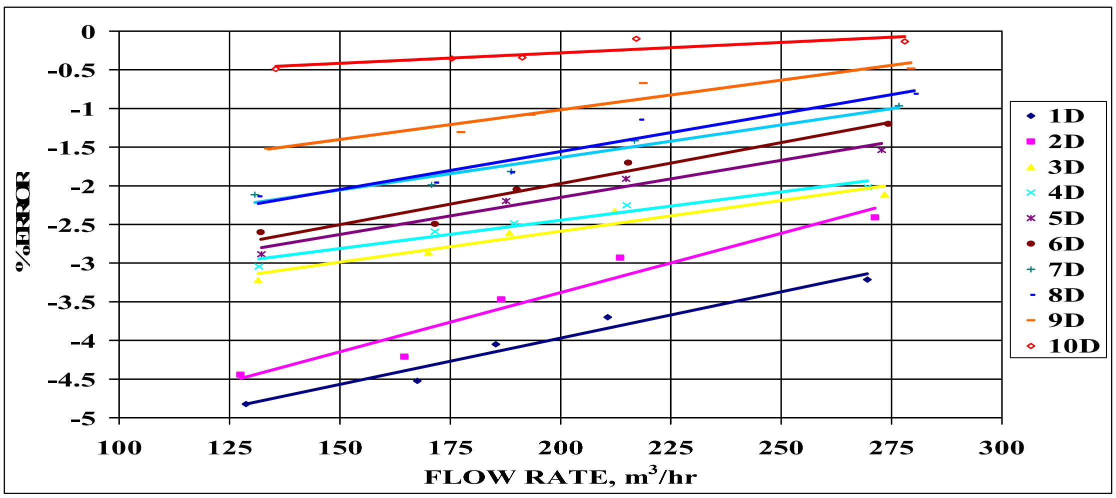


Figure 6.8: 100 mm NB double elbow in plane

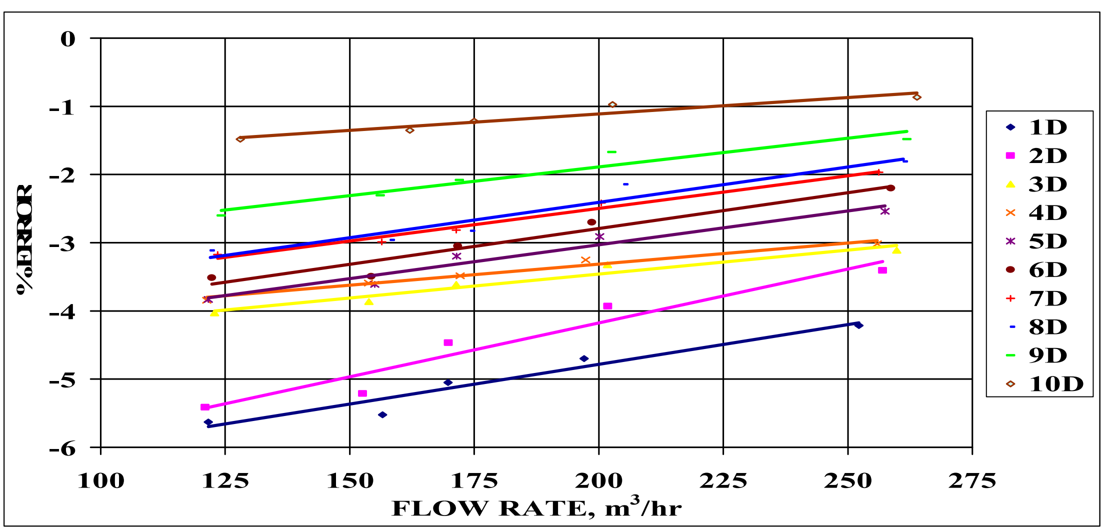


Figure 6.9: 100 mm NB Triple elbow out of plane

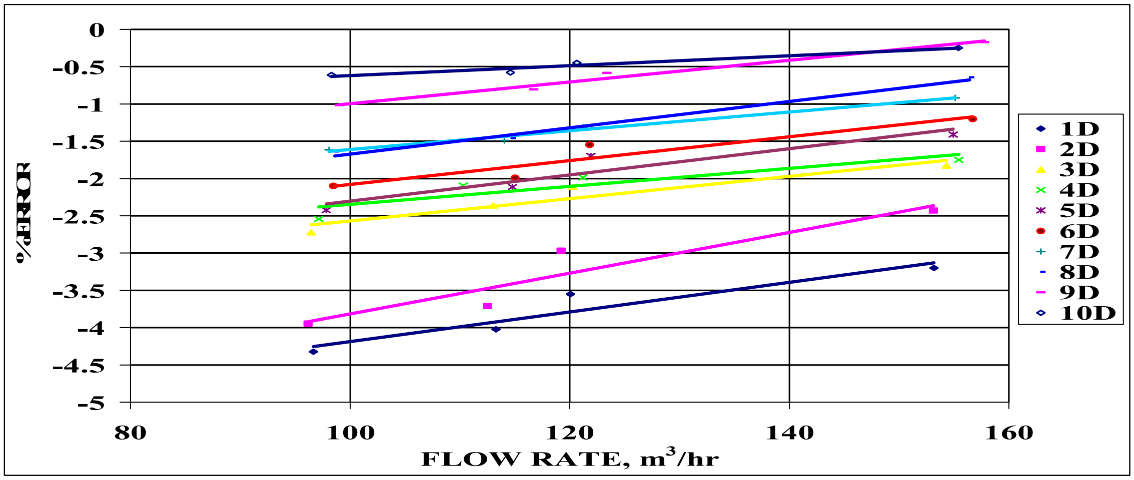


Figure 6.10: 80 mm NB double elbow in plane

It was revealed that with three elbows placed out of plane with flow velocities in range 2m/s to 10 m/s, the errors observed are more than the other two respective cases since the three elbows in different plane generate swirl in pipe downstream of the configurations. The errors observed in these cases are in the range of -0.86 % to -6.12% at different locations.

Thus, all above studies had revealed the extent of deviation in flow rate owing to disturbed flow profiles, triggering of turbulence and swirl produced in pipe line as a result of the presence of above upstream bends.

The present BIS, ISO /IEC standards do not indicate the extent of deviation of measured flow rate from its true value, when recommended straight lengths are not met. On this background an attempt had been made through the present studies to quantitatively co-relate the effect of significant upstream flow conditions on the accuracy of flow measurement using Ultrasonic Flow Meter.

These results may be considered where standard upstream and downstream straight lengths are not available due to site constraints. It is recommended that the flow meters may be got calibrated initially in a high precision laboratory against primary standards and used at site. The extent of possible deviation in flow rate indicated by the meter from true value can be estimated from these research findings. It is also recommended that flow meters installed in such site conditions may be calibrated by simulating the actual piping configuration at site in calibration laboratory.

CHAPTER 7
SITE CONSTRAINTS

Site selection for flow measurement in hydropower plants is governed by a balance between hydraulic suitability, structural feasibility, operational continuity, safety, and cost. Often, compromises are necessary, and indirect or comparative methods (e.g., ultrasonic, index velocity, or model-based calibration) are adopted. Expert evaluation and field validation are essential for selecting an optimal measurement location.

Calibration of flow meters on site, also known as *in-situ calibration*, is carried out to verify and adjust the accuracy of the meter under actual operating conditions — without removing it from the pipeline. The calibration method depends on factors such as the type of flow meter (electromagnetic, ultrasonic, turbine, etc.), the fluid being measured (water, oil, air), and the available site infrastructure.

7.1 CONSTRAINTS IN SITE SELECTION FOR FLOW MEASUREMENT IN HYDROPOWER PLANTS

Accurate flow measurement is essential in hydropower plants for performance evaluation, efficiency testing, water accounting, and regulatory compliance. However, selecting a suitable site for flow measurement involves several technical, hydraulic, structural, and operational constraints.

Hydraulic Flow Conditions

- Non-uniform velocity distribution due to bends, transitions, or fittings affects measurement accuracy.
- Swirling and turbulent flow near intakes, gates, valves, and draft tubes creates unstable readings.
- Insufficient straight length upstream and downstream of the measuring device limits proper flow development.
- Presence of air entrainment in high-head or free-surface zones interferes with certain flow meters.

Geometric and Structural Constraints

- Limited space in existing powerhouses or penstocks restricts installation of flow meters.

- Large penstock diameters make installation of inline meters technically difficult and costly.
- Irregular cross-sections or non-circular conduits complicate velocity-area methods.
- Access constraints for installation, inspection, and maintenance.

Operational Constraints

- Continuous operation requirements may not permit shutdown for meter installation.
- Variable flow regimes (part load, overload, transient conditions) affect calibration validity.
- Rapid load changes and pressure fluctuations influence measurement stability.
- Sediment-laden flows cause abrasion and sensor fouling.

Environmental and Site Conditions

- High sediment concentration leads to wear of mechanical sensors and inaccuracies.
- Floating debris and trash obstruct sensors in open channels.
- Extreme pressure and temperature conditions in high-head plants limit sensor selection.
- Cavitation-prone zones damage instruments and degrade accuracy.

Instrumentation Constraints

- Meter type suitability varies with site conditions (head, velocity, diameter).
- Accuracy requirements may not be achievable at all locations.
- Power supply and signal transmission limitations in remote sites.
- Electromagnetic interference affecting electronic meters.

Calibration and Traceability Issues

- In-situ calibration difficulty in large-diameter penstocks.
- Lack of reference measurement at site for verification.
- Installation effects dominating calibration accuracy.
- Long-term drift due to harsh operating conditions.

Safety Considerations

- High-pressure conduits pose safety risks during installation.
- Confined space hazards in tunnels and penstocks.
- High-velocity flow increases risk to personnel during measurement.

Economic and Practical Constraints

- High cost of large-size flow meters.
- Civil modification costs for meter installation.
- Maintenance costs in inaccessible locations.
- Downtime losses due to plant shutdown.

Regulatory and Contractual Constraints

- Statutory requirements on measurement accuracy and location.
- Dispute resolution needs between utilities and regulators.
- Compatibility with existing monitoring systems.

Typical Preferred Locations (with Limitations)

Location	**Advantage**	**Constraint**
Intake channel	Easy access	Flow disturbance
Penstock (straight reach)	Enclosed flow	Installation difficulty
Turbine inlet	Proximity to energy conversion	Severe turbulence
Tailrace channel	Easy measurement	Backwater effects

Selection Criteria for Flow Measurement Method

Parameter	Consideration
Pipe diameter	Small → mechanical, Large → ultrasonic/electromagnetic
Water quality	Dirty → Doppler / flume
Accuracy needed	High → electromagnetic / gravimetric
Power availability	None → mechanical
Maintenance	Low → ultrasonic
Budget	Low → orifice / weir

The elevation of the piping circuit at metering section may be raised to ensure that the flow is full in the piping circuit and to avoid partial flow at flow metering section.

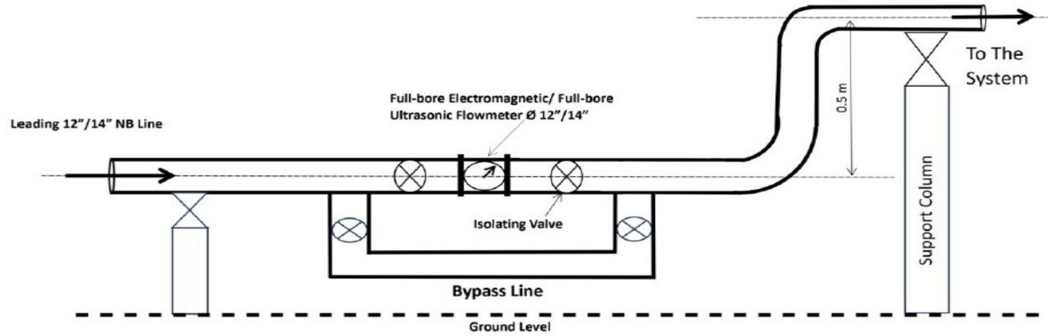


Figure 7.1: 100 mm NB Triple elbow out of plane

A general characteristic of fixed type flow meters is given in below table for the proper selection and installation of flow meter at site

Flow Meter Type	Recommended Application	Typical Turn down Ratio	Pressure Drop	Typical Accuracy %	U/S Pipe Diameter (D)	Effects of Viscosity	Relative Cost	Remarks
Orifice	Clean liquids & gases	4:1	medium	$\pm 2 - \pm 4$ of full scale	10-30	high	low	-
Venturi	Clean liquids & gases	4:1	low	± 1 of full scale	5-20	high	medium	-
Flow Nozzle	Clean liquids & gases	4:1	low to medium	$\pm 1 - \pm 2$ of full scale	10-30	high	medium	-
Pitot Tube	Clean liquids & gases	3:1	very low	$\pm 3 - \pm 5$ of full scale	20-30	low	high	-
Rotameter	Clean, dirty liquids & gases	10:1	medium	$\pm 1 - \pm 10$ of full scale	None	medium	low	-
Positive Displacement	Clean liquids & gases	10:1	high	± 0.5 of flow rate	none	high	medium	-

CHAPTER 8
FLOW MEASUREMENT IN PIPES

The Ministry of Jal Shakti (MoJS) in India, through flagship programs like the *Jal Jeevan Mission (JJM)*, places strong emphasis on not only constructing rural water supply infrastructure but *ensuring reliable, measurable, and sustainable delivery of potable water* to every household. Monitoring water flow in distribution pipes is foundational to achieving service delivery objectives, efficient operations, and accountability in public water systems.

8.1 POLICY AND OPERATIONAL CONTEXT

Jal Jeevan Mission’s Service Delivery Focus

Under JJM, the definition of successful implementation has evolved from merely laying pipelines to *verifiable service delivery of water* — popularly articulated as “Har Ghar Jal” — Functional Tap Water for every rural household.

The mission’s Operational and Technical Guidelines explicitly state that *“what cannot be measured cannot be managed”*, highlighting the need for data on *quantity of water supplied daily, quality, and distribution performance*.

Mandated Monitoring Framework

The MoJS, through technical expert committees and guidelines, recommends integrating sensors, flow meters, IoT networks, and dashboards at key nodes in the water supply system, including:

- Bulk flow meters at service reservoir outlets,
- Flow measurement at discrete clusters or domestic distribution areas,
- Water level and pressure sensors at sources and storage,
- Chlorination monitoring,
- Automated data capture systems linked to central dashboards.

Technical Rationale for Flow Measurement

Accurate flow measurement in water distribution pipes under government schemes serves multiple technical, managerial, and governance objectives:

Verification of Water Supply Delivery

- **Evidence of service delivery:** Flow data confirms that water actually flows through pipes to the designated distribution nodes and ultimately to households. Without measurement, reported connectivity may not reflect actual supply performance.

- **Performance benchmarking:** Quantifies total water supplied daily and per capita, enabling assessment against service targets (e.g., litres per capita per day).

Operational Efficiency and System Health

- **Network performance monitoring:** Real-time flow rates help detect anomalies such as *zero flow conditions, pressure drops,* or *unplanned stoppages*. These insights allow timely corrective actions.
- **Demand management:** Flow data supports better understanding of daily and seasonal water demand patterns, enabling optimization of pump operations and storage utilization.

Leak Detection and Loss Control

- Water distribution systems are prone to leakages and unauthorized draw-offs. Measuring flow at strategic points helps establish water balances and pinpoint network losses — a critical step in reducing wastage and non-revenue water.

Quality and Safety Integration

- Flow measurement integrates with monitoring of water quality (e.g., chlorine residuals, turbidity) and pressure sensors, forming a holistic *service health index* that guides operators and regulators.

Data-Driven Decision Making

- Analytics and predictive maintenance: Modern IoT platforms ingest flow data into analytics engines and dashboards, enhancing planning for repairs, expansions, and budgeting.
- Policy assessment: Aggregated flow data enables macro-level evaluation of scheme performance across regions and over time.

Transparency and Accountability

- Digital flow data, when published in dashboards or linked with unique scheme identifiers (e.g., RPWSS IDs), improves transparency, reporting accuracy, and accountability of public water supply operations.

8.2 TECHNICAL IMPLEMENTATION CONSIDERATIONS

Types of Measurement Devices

Depending on system scale and accuracy requirements, appropriate devices include:

- **Bulk flow meters:** Mounted on main transmission or distribution lines to measure total flow (e.g., ultrasonic, electromagnetic meters).
- **Secondary flow sensors:** At zonal, cluster, or community tap levels.

- **Level and pressure sensors:** To support hydraulic modeling and pump control.

Note: Device selection should balance cost, accuracy, reliability, ease of installation, and maintainability in rural environments.

Integration with Digital Architecture

Modern design under Jal Shakti schemes integrates flow measurement with digital systems:

- IoT networks and cloud platforms for automated data capture.
- Dashboards and GIS mapping for visualizing flow along the network.
- Unique identifiers (RPWSS IDs) to maintain traceable records of each piped scheme and its performance metrics.

8.3 BENEFITS AND OUTCOMES

Improved Service Delivery

- Water supplied is reliably quantified and confirmed in near-real time.
- Enables progressive improvement in supply hours and consistency.

Better Resource Management

- Supports planning for future demand, drought conditions, and equitable distribution.

Financial Accountability

- Accurate measurement reduces guesswork, supports funding prioritization, and can link performance to incentive structures for local governance bodies.

Operational Resilience

- Early detection of issues (leaks, breakdowns) leads to reduced downtime and maintenance costs.

8.4 CHALLENGES AND IMPLEMENTATION RISKS

While technically compelling, flow measurement deployment faces issues such as:

- Cost of sensors and connectivity in remote areas.
- Power supply and calibration challenges.
- Maintenance capacity at local levels.
- Data reliability and integration with legacy systems.

Efforts are underway to pilot scalable solutions and build local technical capacities.

Water flow measurement in pipes is essential under the Ministry of Jal Shakti’s schemes to transition from *infrastructure deliverables* to *verified and accountable service delivery*. Accurately measuring flow enables performance monitoring, operational control, quality assurance, and evidence-based governance — critical elements in achieving universal access to safe drinking water.

CHAPTER 9

FLOW MEASUREMENT IN OPEN CHANNEL USING ADCP

9.1 FLOW MEASUREMENT IN OPEN CHANNELS USING ADCP (ACOUSTIC DOPPLER CURRENT PROFILER)

Acoustic Doppler Current Profiler (ADCP) is a modern, non-intrusive instrument widely used for measuring flow velocity and discharge in open channels such as rivers, canals, drains, and estuaries. It is especially useful where conventional methods are difficult, unsafe, or inaccurate.

9.2 PRINCIPLE OF OPERATION

ADCP works on the Doppler effect principle.

- The instrument transmits acoustic (sound) pulses into the water.
- These pulses are reflected back by suspended particles (sediment, plankton, bubbles).
- The frequency shift between transmitted and received signals is proportional to the velocity of water.
- Using multiple acoustic beams (usually 3 or 4), the ADCP calculates 3-D velocity components of flow.

9.3 ADCP SYSTEM COMPONENTS

- Transducer head (emits and receives acoustic beams)
- Beam configuration (Janus type, 20–30° inclination)
- Depth sensor
- Compass and tilt sensors
- Data acquisition and processing unit
- GPS (optional) for geo-referenced measurements

9.4 TYPES OF ADCP USED IN OPEN CHANNELS

1. **Boat-mounted ADCP**
    - Used for rivers and large canals
    - Traversed across the channel
2. **Moving-boat ADCP**
    - Measures discharge by repeated cross-sectional transects
3. **Fixed or Side-looking ADCP**
    - Installed permanently on river banks or structures
    - Suitable for continuous monitoring
4. **Handheld or Wading ADCP**
    - For small streams and shallow channels

9.5 MEASUREMENT METHODOLOGY

Step 1: Site Selection

- Straight reach with uniform flow
- Avoid excessive turbulence, eddies, and backwater effects
- Adequate depth (generally >0.3 m)

Step 2: Cross-Section Survey

- Channel width and depth profile measured
- Multiple vertical bins formed along water column

Step 3: Velocity Measurement

- Velocity measured in **depth cells (bins)**
- Near-surface and near-bed velocities are extrapolated

Step 4: Discharge Computation

$$Q=\sum(V_i \times A_i)$$

Where:

- V_i = velocity in each cell
- A_i = corresponding area

ADCP software automatically integrates velocity over the cross-section to give total discharge.

9.6 ADVANTAGES OF ADCP IN OPEN CHANNEL FLOW MEASUREMENT

- Non-contact and safe (no need to enter water)
- Rapid measurements (complete discharge in minutes)
- Suitable for flood conditions
- Measures full velocity profile
- High accuracy (±2–5%)
- Ideal for large rivers and unsteady flows

9.7 LIMITATIONS

- Requires suspended particles for signal reflection
- Reduced accuracy in very shallow water
- Errors near surface and bed (blanking zones)
- Expensive equipment
- Skilled operation and data interpretation required

9.8 ACCURACY AND CALIBRATION

- Factory calibrated
- Field validation using:

  - Current meter
  - Electromagnetic flow meter
- Uncertainty depends on:
  - Flow turbulence
  - Boat speed and alignment
  - Bed roughness

9.9 APPLICATIONS

- River discharge measurement
- Flood monitoring and forecasting
- Sediment transport studies
- Hydropower and irrigation projects
- Environmental flow assessment
- Validation of hydraulic models
- National programmes (JJM, NGP, Atal Jal)

9.10 CWPRS AND NATIONAL WATER PROGRAMS

- Supports high-accuracy discharge data
- Useful for river basin studies and flood hydraulics
- Validation of hydraulic structures and models
- Supports Ministry of Jal Shakti schemes through reliable flow data

ADCP is a state-of-the-art, reliable, and efficient tool for open channel flow measurement. Its ability to measure full velocity profiles and discharge under difficult conditions makes it indispensable for modern hydrology, river engineering, and national water management programmes.

An **Acoustic Doppler Current Profiler (ADCP)** is an oceanographic instrument used to **measure water current speed and direction** over a range of depths. It works by emitting **sound pulses** into the water and analysing the **Doppler shift** of the echoes reflected from particles suspended in the water (such as sediment). By measuring how the frequency of the returned sound changes, the ADCP calculates the **velocity of water movement** at different depths. ADCPs are widely used in **rivers, lakes, oceans, and coastal waters** for hydrology, oceanographic application. One such type of its applicability is used in one of our major public works associated project in Bihar where the proposal of government is to facilitate the transfer of water from the Ganga River to agricultural lands in Bihar. This will ensure the efficient and uninterrupted flow of water to the targeted irrigation areas. This cutting-edge infrastructure is expected to significantly enhance the region's irrigation capacity, thereby supporting the agricultural needs of local farmers and contributing to overall water resource management in the state. Major problem in this project is too dealt with the availability of water to the current proposed pump house to be executed along with the continuous and uninterrupted supply of water to the existing pump house. Therefore a survey was planned to evaluate and monitor the discharge capacity near the pump house location with the help of Acoustic Doppler Current Profiler (ADCP) across the river.

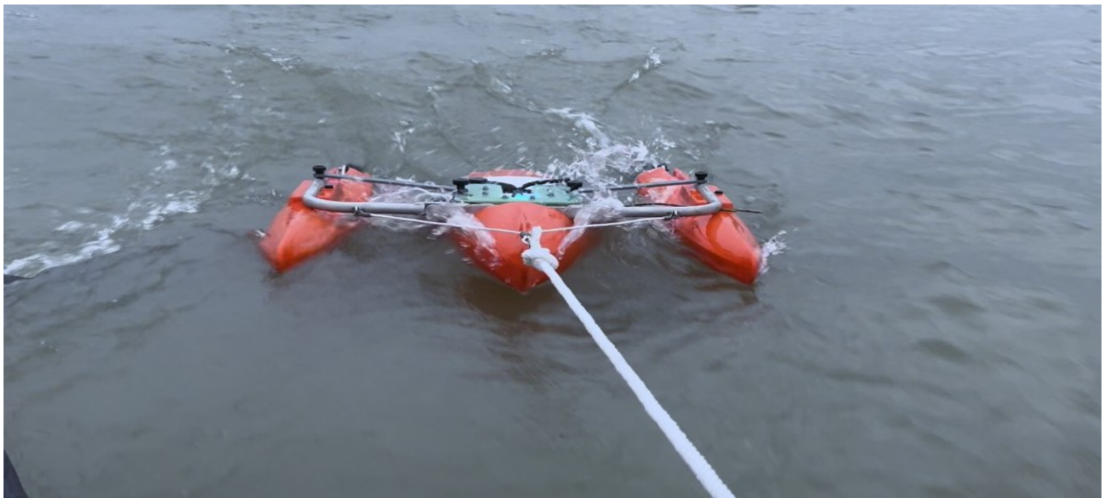


Figure 9.1: Discharge Measurement in Ganga River using ADCP

Measurements using Acoustic Doppler Current Profilers (ADCP)

Acoustic Doppler Current Profilers (ADCP) is sophisticated instrument used for measuring water velocity and discharge in rivers, lakes, and oceans. They utilize the Doppler effects to measure the speed of particles in the water, providing detailed profiles of flow velocity across different depths. Here's an overview of how they work and their applications:

1. Principle of Operation:
   - ADCPs emit sound pulses (acoustic signals) into the water.
   - As these sound waves hit suspended particles in the water, they are reflected back to the instrument.
   - The frequency shift of the returned sound waves (due to the motion of the particles) is analysed to calculate the velocity of the water.
2. Multi-Beam System:
   - ADCPs typically use multiple beams (usually four or more) angled to measure velocities in different directions.
   - This allows for the measurement of three-dimensional flow velocities at various depths.
3. Depth Profiling:
   - By continuously sending out acoustic signals and receiving echoes, ADCPs can create a profile of water velocity at different depths (often divided into depth cells).
4. Data Processing:

- The collected data is processed to calculate mean velocities and discharge using the velocity-area method, where the cross-sectional area of the river is combined with velocity data.

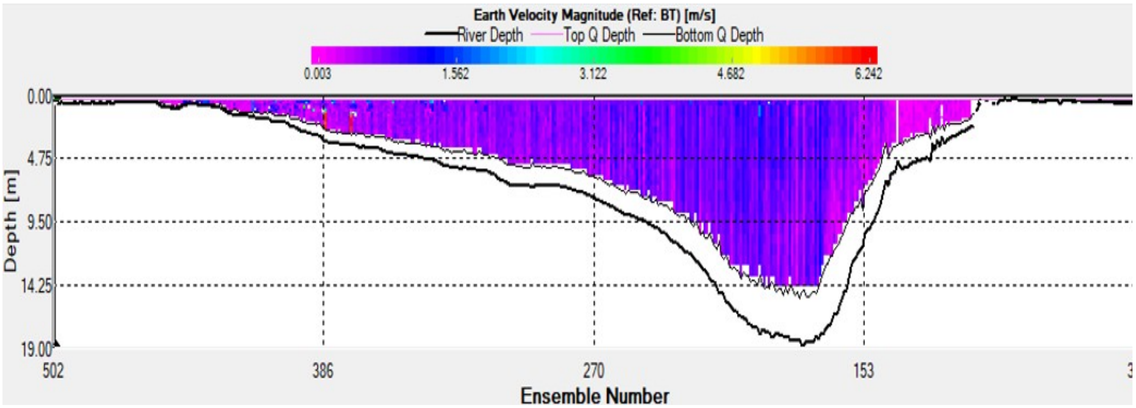


Figure 9.2: Pixel data collected using ADCP at existing pump house location

Typical Studies Carried with ADCP

❖ Onsite Efficiency Test of Six Numbers of Screw Turbine Plants in Vadodara Branch Canal of SSNNL, Gujarat through M/s Jash Engineering Ltd., Indore.The performance of the on-site efficiency test of six in nos. screw turbine units of Sardar Sarovar Narmada Nigam Ltd, Vadodara, Gujarat. The Archimedes Screw Turbine (AST) consists of key components, including the screw shaft, housing (web), drive shaft and bearings. These components work together to convert water flow into rotational motion, enabling energy generation.

Figure 9.3: Onsite Efficiency Test of Screw Turbine Plants in Canal of SSNNL

CHAPTER 10
CUSTODY TRANSFER OF WATER

Accurate flow measurement is the backbone of custody transfer. Custody transfer of water refers to the formal handover of responsibility, ownership, or accountability for a defined quantity of water from one entity to another at a specified transfer point, based on accurate and traceable flow measurement. It is analogous to custody transfer in oil and gas and is increasingly relevant in bulk water supply, inter-basin transfers, urban utilities, irrigation projects, and reuse systems.

10.1 PURPOSE OF CUSTODY TRANSFER

- Ensure **transparent and accountable water delivery**
- Enable **accurate billing and cost recovery**
- Support **inter-state, inter-agency, and public–private arrangements**
- Reduce disputes related to quantity and losses
- Facilitate **water auditing and regulation**

10.2 CUSTODY TRANSFER POINTS

Custody transfer typically occurs at:

- River off-take points (barrages, weirs)
- Reservoir releases
- Bulk supply mains
- Canal head regulators
- STP treated effluent delivery points
- Industrial or urban bulk water supply interfaces

These points must be **clearly demarcated and mutually agreed** by all stakeholders.

10.3 ROLE OF FLOW MEASUREMENT

Accurate flow measurement is the backbone of custody transfer.

Key requirements:

- High accuracy and repeatability
- Traceability to national standards
- Continuous and tamper-proof measurement
- Data logging and secure transmission

10.4 COMMON INSTRUMENTS:

- Electromagnetic flow meters

- Ultrasonic (transit-time) flow meters
- Weirs and flumes (with calibrated rating curves)
- Acoustic Doppler systems for open channels

10.5 MEASUREMENT STANDARDS AND ACCURACY

- Meter selection based on flow range, water quality, and hydraulic conditions
- Accuracy typically ±1% to ±2% for custody transfer applications
- Compliance with ISO / BIS / OIML standards
- Regular calibration by NABL-accredited laboratories

10.6 OPERATIONAL AND LEGAL FRAMEWORK

Custody transfer arrangements are governed by:

- Water supply agreements / MoUs
- Interstate water-sharing accords
- Regulatory guidelines and tribunal awards
- Environmental clearance conditions

Key provisions include:

- Defined transfer point and responsibility
- Measurement methodology
- Data ownership and dispute resolution mechanism
- Calibration and audit frequency

10.7 APPLICATIONS OF CUSTODY TRANSFER OF WATER

- Inter-state and inter-basin water transfers
- Urban bulk water supply to ULBs
- Industrial water supply and PPP projects
- Treated wastewater reuse and sale
- Irrigation system deliveries

10.8 IMPORTANCE OF CUSTODY TRANSFER

- Promotes **equity and transparency**
- Enhances **water use efficiency**
- Enables **revenue assurance**
- Supports **regulatory compliance**
- Builds trust among stakeholders

10.9 ROLE OF CWPRS

CWPRS support custody transfer through:

- Development of flow measurement standards
- Calibration of high-capacity flow meters
- Hydraulic modeling of transfer structures
- Technical advisory to MoJS, CWC, NWDA, and States

Custody transfer of water ensures that water as a measurable, valuable resource is transferred in a transparent, accurate, and legally defensible manner. Reliable flow measurement, robust standards, and institutional oversight are essential for effective custody transfer and sustainable water governance.

CHAPTER 11
CONCLUSION

The Technical Memorandum conclusively demonstrates that the flow calibration and testing facilities at CWPRS provide the scientific and metrological foundation required to support these objectives in a transparent, accountable, and technically robust manner.

The gravimetric and volumetric calibration facilities operated by the Hydraulic Machinery Division enable primary realization of flow using SI units, ensuring the highest level of measurement accuracy and traceability. These facilities directly support calibration of flow meters, performance testing of pumps, verification of hydraulic systems, and validation of field measurements under real operating conditions. The documented uncertainties, standardized procedures, and compliance with ISO and BIS standards position CWPRS as a national reference for liquid flow measurement.

The memorandum clearly establishes that national schemes such as **Jal Jeevan Mission**, **National Water Mission**, and **Dam Rehabilitation and Improvement Project** depend fundamentally on accurate flow data for service verification, efficiency improvement, safety assurance, and regulatory compliance. Calibration of bulk water meters under JJM ensures correct reporting of litres per capita per day, reduction of non-revenue water, and sustainability of rural water supply systems. Under NWM, calibrated flow measurements enable water audits, pump efficiency improvements, and achievement of targeted gains in water-use efficiency. For DRIP, accurate discharge measurement and hydraulic assessment are essential for safe dam operation, rehabilitation planning, and downstream risk management.

Beyond individual schemes, the CWPRS flow calibration facility plays a systemic role in strengthening governance by enabling performance-based monitoring, auditability of public investments, and data-driven decision-making. The experimental research and field studies conducted by CWPRS further bridge the gap between laboratory standards and site realities, addressing installation effects, flow disturbances, and practical constraints.

In conclusion, the CWPRS flow calibration and testing infrastructure is not merely a laboratory facility but a **national asset** that underpins the successful implementation of India's water-related programme. By ensuring accurate, reliable, and traceable flow measurement, CWPRS directly contributes to sustainable water management, efficient infrastructure operation, and long-term national water security.