Online training of SAARC Professionals on Small, Mini and Micro Hydro Power Generation
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# Measurement of Performance of SMMHP Plants

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# CONTENTS

1. Purpose of performance measurements
2. Instruments for Measurement of parameters
3. Methods of efficiency measurements
4. Recommendations and report writing of performance measurements

# LEARNING OBJECTIVES

To understand the procedure and importance of performance measurement.

# OBJECTIVES OF PERFORMANCE TESTING

- To confirm that all parts and systems in the power station are performing their assigned functions correctly.

- To confirm that the power station is operating efficiently as per the design.

# SCOPE OF PERFORMANCE TESTING

- Inspection of all parts, systems, station auxiliaries.
- Operational checks on simpler devices / systems.
- Error checks on measuring instruments.
- Secondary injection tests on protective relays.
- Operational tests on control systems.
- Measurement of critical parameters.
- Measurement of maximum power output of units.
- Verification of turbine / unit / station efficiency.
- Verification of efficiency with load/gate opening/ valve opening.

# EFFICIENCY TEST ON GENERATING UNITS

# MEASUREMENTS REQUIRED FOR DISCHARGE & HEAD METHODS

- $\eta = \dfrac{P_e}{P_h}$
- $P_h = \rho\, g\, HQ$ in watts

where

$\rho$ = actual density of water in $kg/m^3$

$g$ = actual acceleration due to gravity of earth in $m/s^2$

$H$ = net head in m

$Q$ = discharge rate in $m^3/s$

- 3 parameters to be measured : $P_e$, Q, H

# LOSSES INCLUDED

- Turbine losses
- Draft tube losses
- Losses in the auxiliaries of turbine and  generator
- Losses in speed increaser (if present)
- Generator losses
- Losses in the excitation system of generator

# METHODS OF UNIT EFFICIENCY MEASUREMENT

Two methods as per IEC-60041:

- Thermodynamic method
  For high heads only

- Discharge and head measurement method
  For all heads

# HEAD & DISCHARGE METHODS

# ELECTRICAL POWER MEASUREMENT

- Reference Meter
  - Portable digital wattmeter
  - Accuracy should be 0.2% or better
  - 3-phase, 3W & 4W capabilities
  - Built-in integrator & timer for average power
- Connect in parallel to panel wattmeter
- CT accuracy should be 0.5%, preferably 0.2%
- VT accuracy should be 0.5%, preferably 0.2%
- If TTB or terminals with sliding links are provided in
- the metering panel, then no shut down is required

- $P_e$ = Reference meter reading x CTR x VTR

# PRESSURE HEAD MEASUREMENT (IEC-60041)

- For Head Measurement in Pressure Channels
  - Liquid-column manometer
  - Dead-weight manometer
  - Spring pressure gauge
  - Electronic pressure transducer

- For Head Measurement in Open Channels
  - Liquid-column manometer
  - Gas purge (bubbler) method
  - Immersible pressure transducer

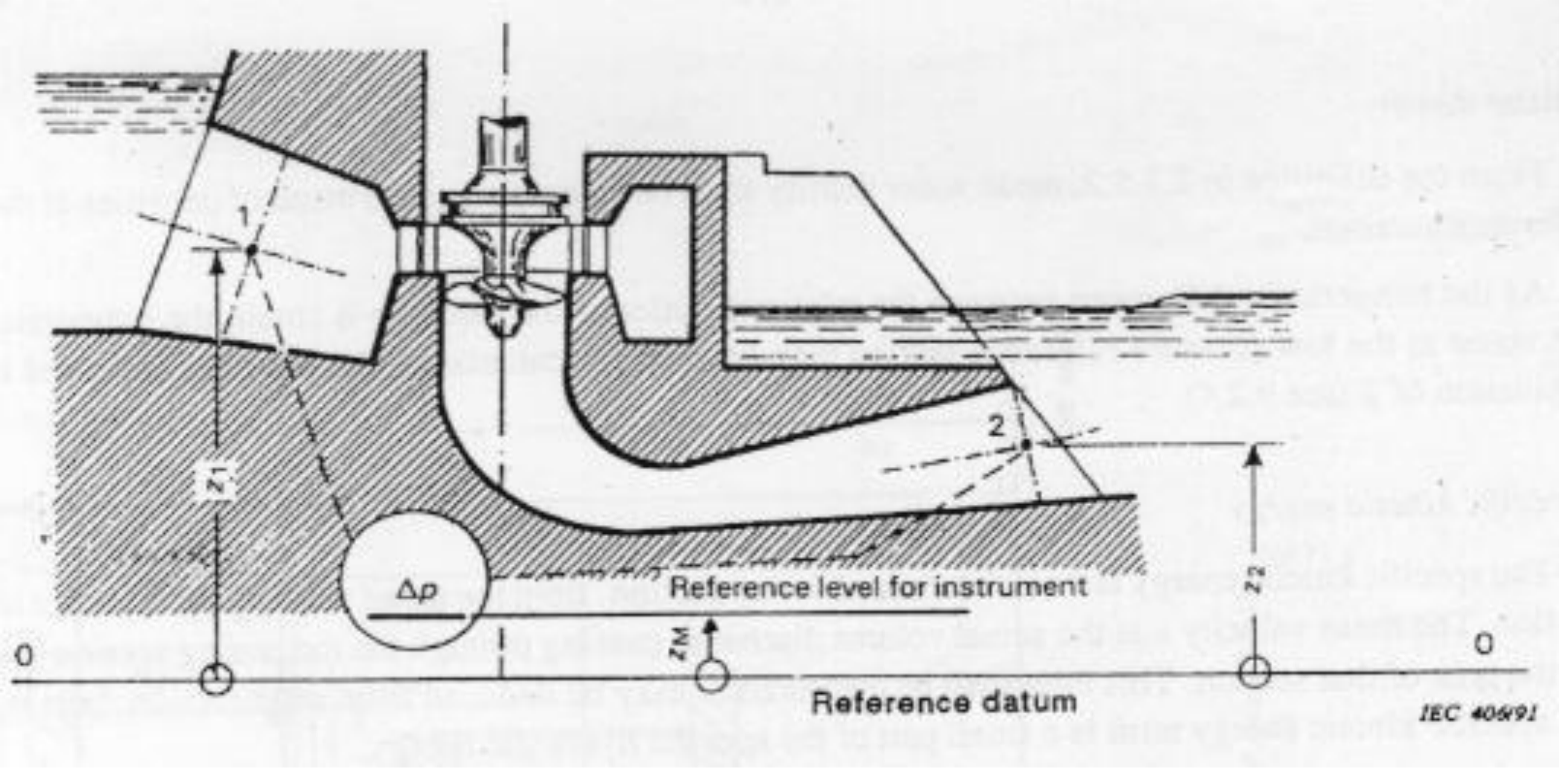
# Free Water Level Measurement in Open Channels (IEC-60041)

- Plate gauge
- Point/hook gauge
- Float gauge
- Staff gauge
- Ultrasonic level sensor

# Head Measurement: Case 1

- Differential pressure transducer
- Low head machine

$$H = \frac{\Delta p}{\rho g} + \frac{v_1^2 - v_2^2}{2g}$$



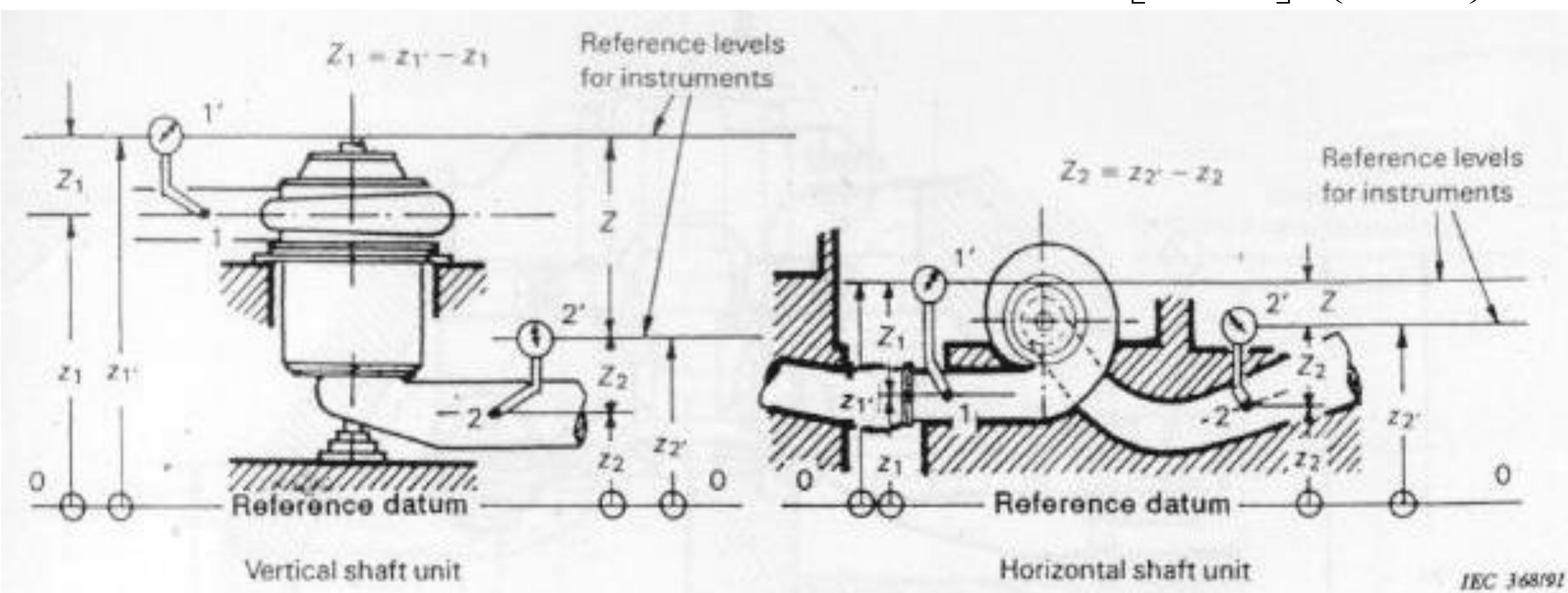

IEC-60041

# Head Measurement: Case 2

- Separate pressure transducers
- Low/Medium head machines

$$H = \left[ z_1' + \frac{p_1'}{\rho g} + \frac{v_1^2}{2g} \right] - \left[ z_2' + \frac{p_2'}{\rho g} + \frac{v_2^2}{2g} \right]$$

$$= \left( z_1' - z_2' \right) + \left[ \frac{p_1' - p_2'}{\rho g} \right] + \left( \frac{v_1^2 - v_2^2}{2g} \right)$$



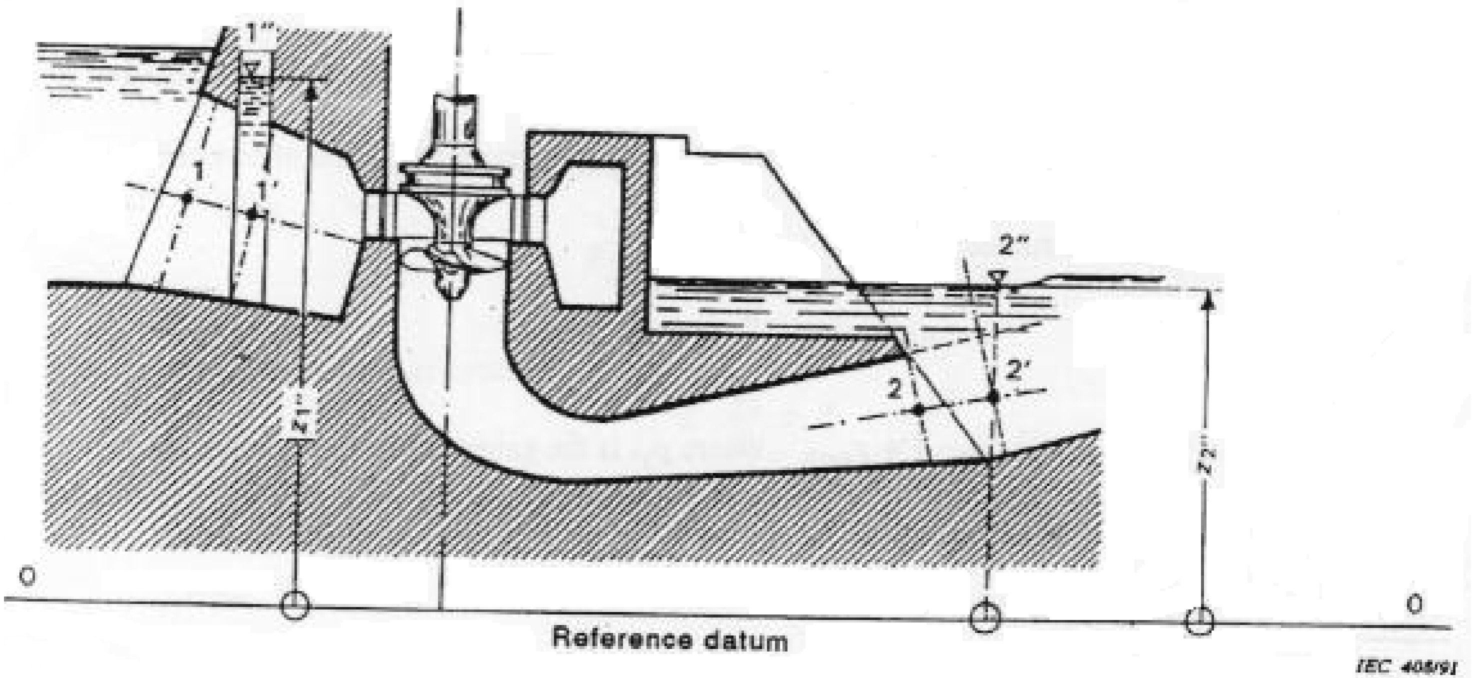

IEC-60041

# Head Measurement: Case 3

- Level Sensors
- Low/Medium head machines

$$H = \left[ z_1'' + \frac{v_1'^2}{2g} \right] - \left[ z_2'' + \frac{v_2'^2}{2g} \right]$$

$$= \left( z_1'' - z_2'' \right) + \left( \frac{v_1'^2 - v_2'^2}{2g} \right)$$



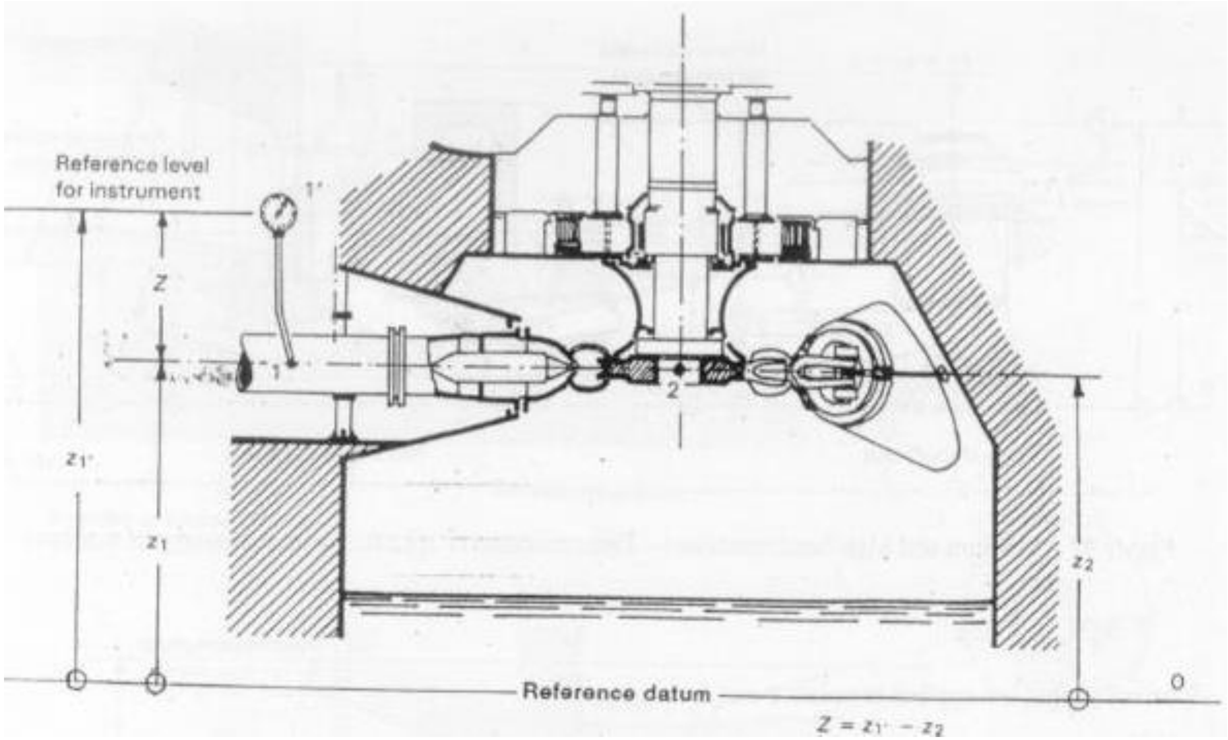

IEC-60041

# Head Measurement: Case 4

- Vertical axis Pelton turbine
- Pressure transducer at inlet

$$H = \left[ z_1' + \frac{p_1'}{\rho g} + \frac{v_1^2}{2g} \right] - (z_2)$$

$$= \frac{p_1'}{\rho g} + z + \frac{v_1^2}{2g}, \text{where } z = z_1' - z_2$$



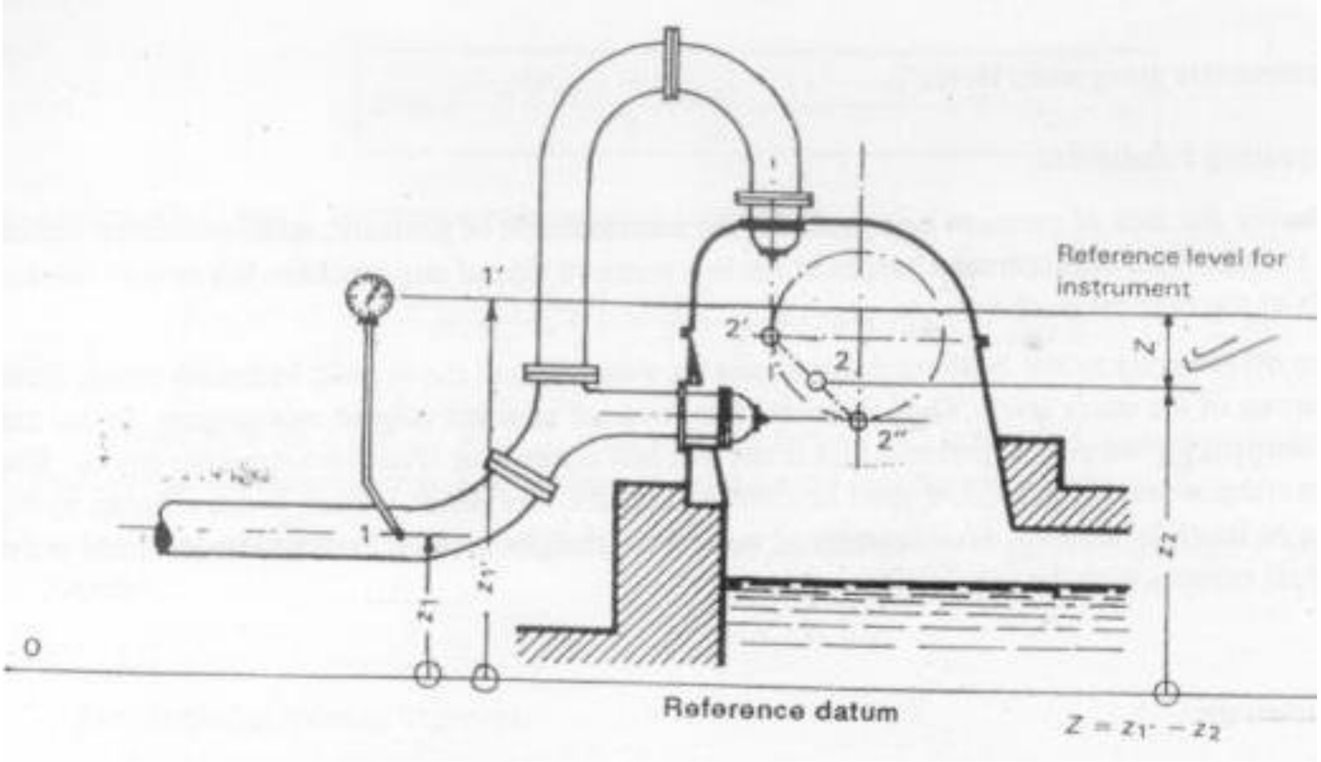

IEC-60041

# Head Measurement: Case 5

- Horizontal axis Pelton turbine
- Pressure gauge at inlet

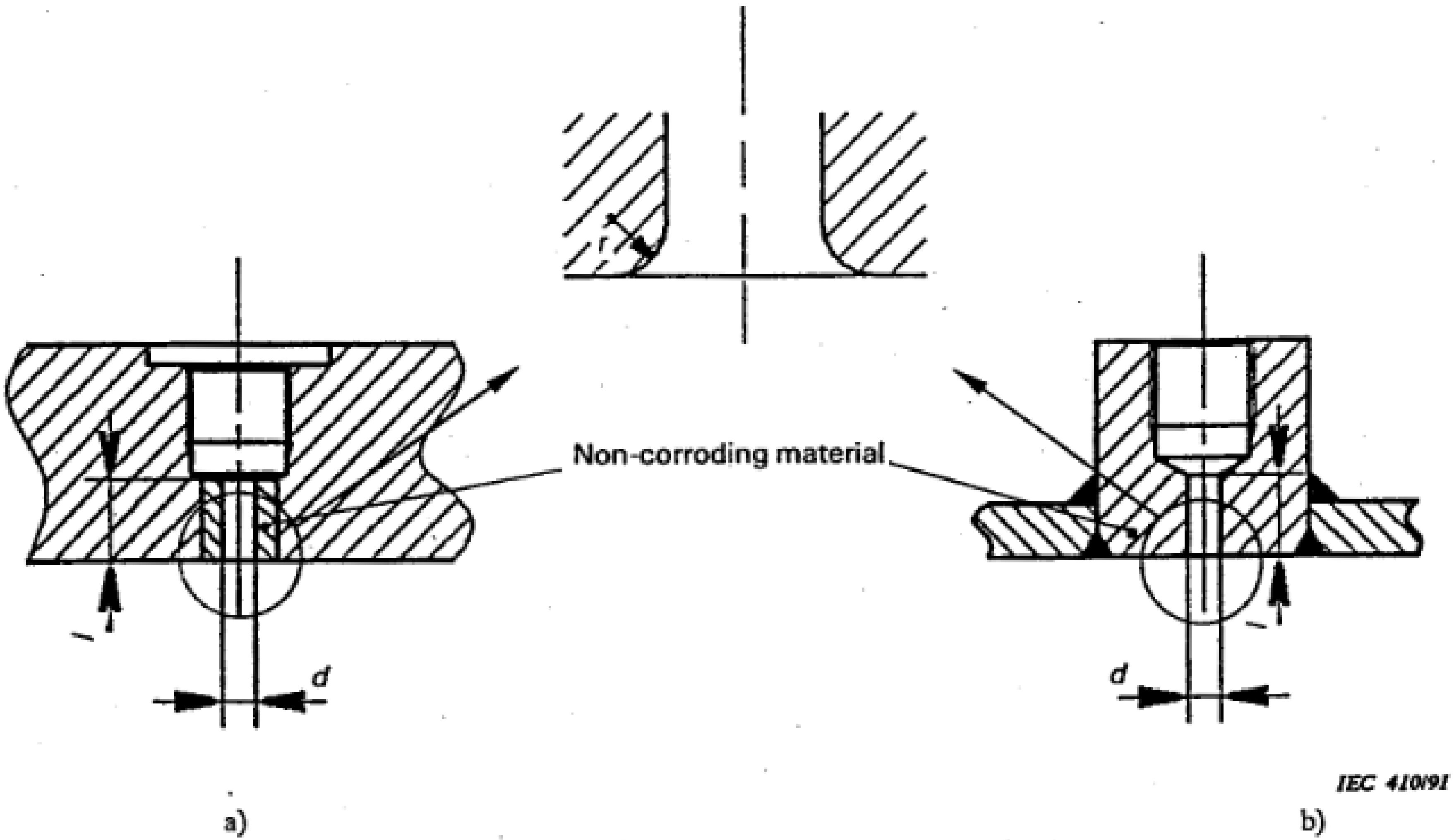
$$H = \left[ z_1' + \frac{p_1'}{\rho g} + \frac{v_1^2}{2g} \right] - (z_2)$$

$$= \frac{p_1'}{\rho g} + z + \frac{v_1^2}{2g}, \text{where } z = z_1' - z_2$$




IEC-60041

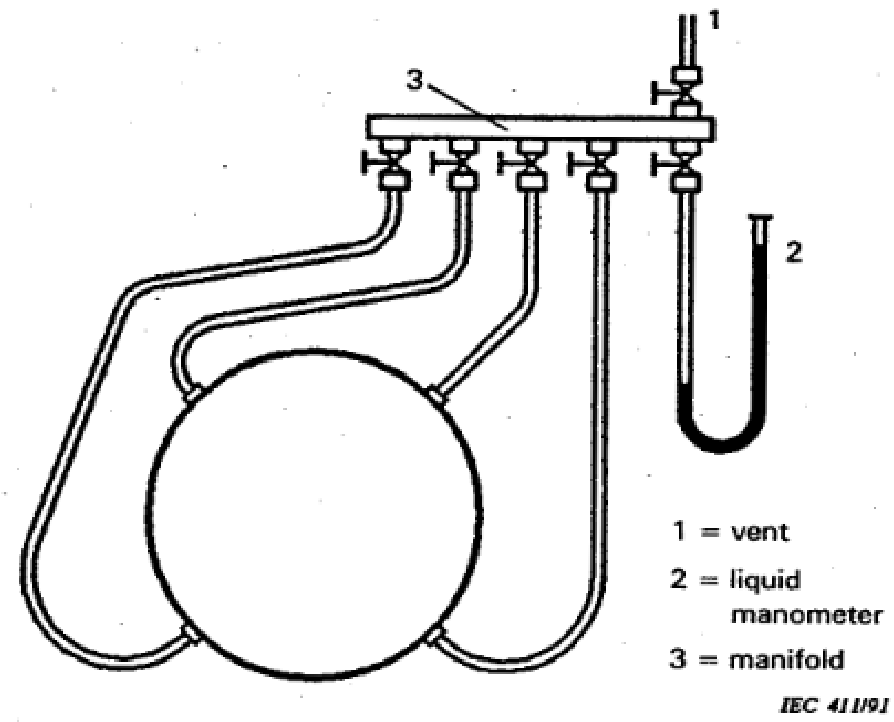
# PRESSURE TAP DETAILS FOR INLET PRESSURE MEASUREMENT




$d = 3\ \text{mm à}\ 6\ \text{mm} \qquad \ell \geq 2d \qquad r \leq d/4$

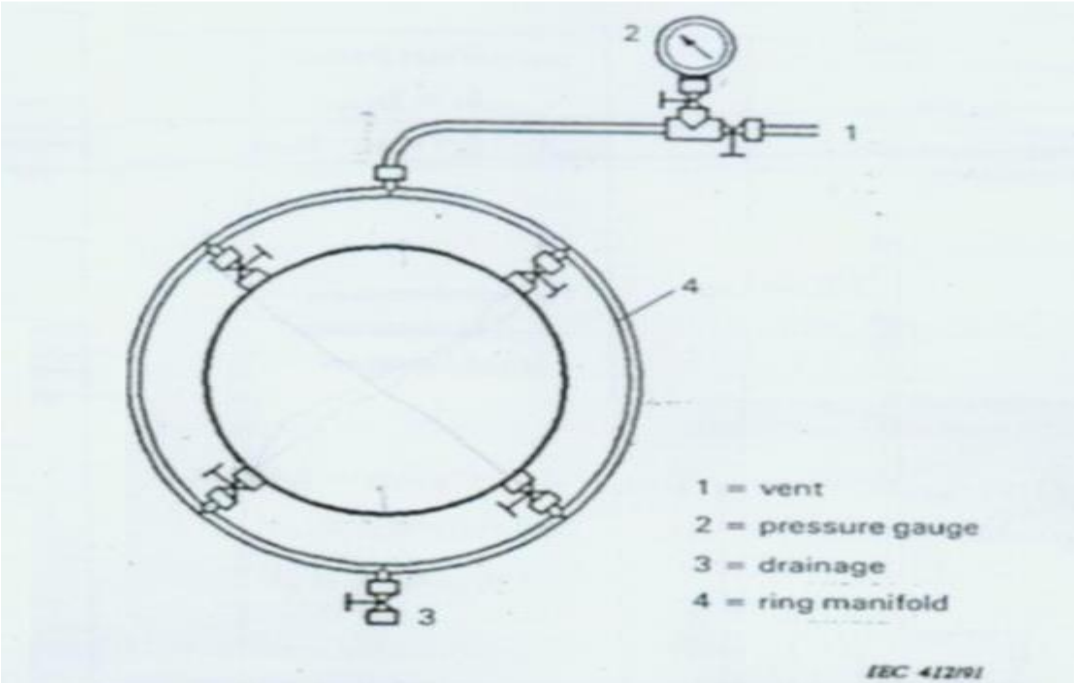
(Source: IEC 60041)

# PRESSURE TAPS CONNECTED THROUGH CONNECTING PIPES TO BOX-TYPE MANIFOLD




(Source: IEC 60041)

# PRESSURE TAPS CONNECTED THROUGH RING-TYPE MANIFOLD TO PRESSURE GAUGE



Pressure taps connected through ring manifold to pressure gauge

(Source: IEC 60041)

# DISCHARGE MEASUREMENT WITH CURRENT METERS

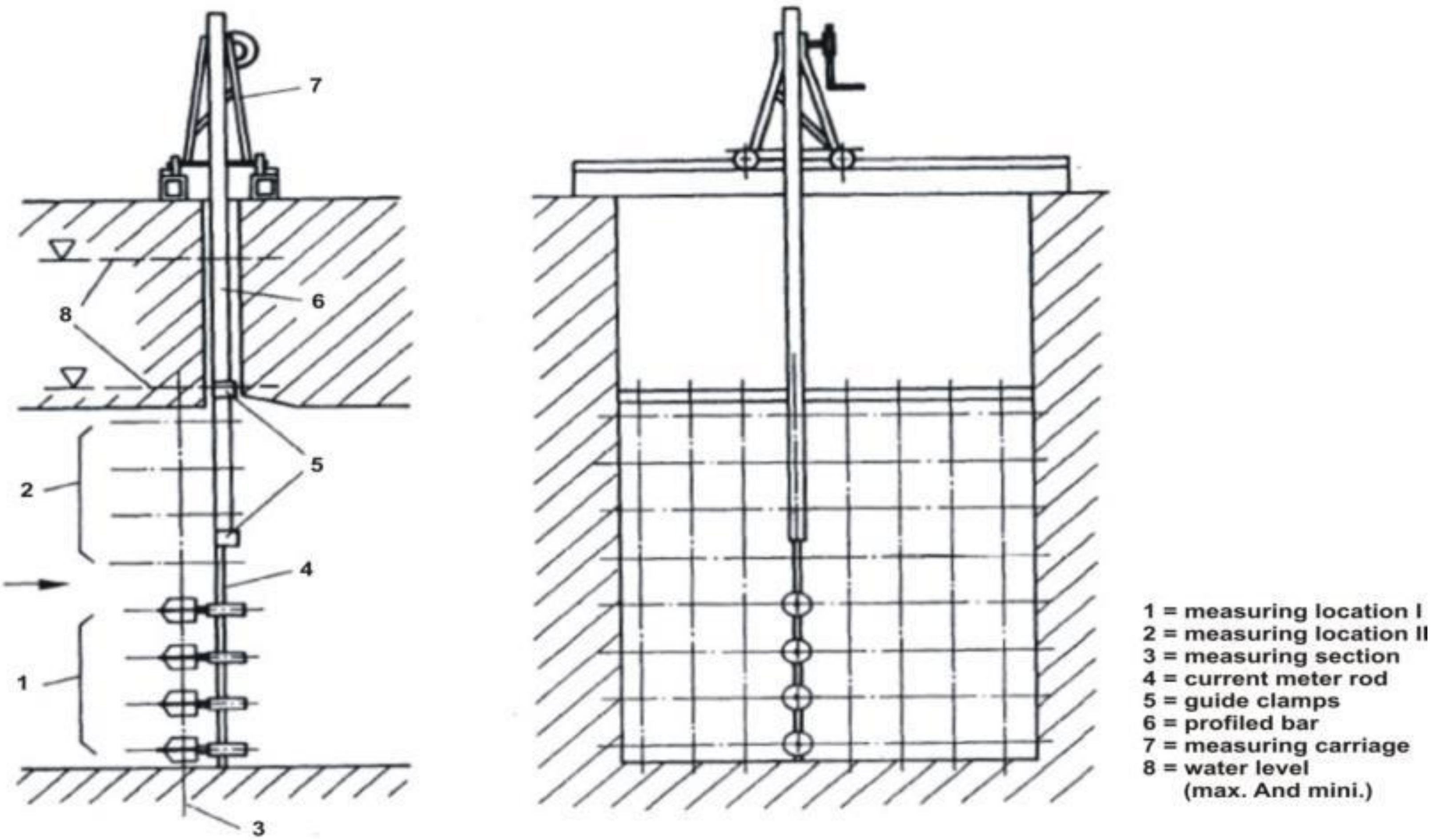
# DISCHARGE MEASUREMENT WITH CURRENT METERS IN PRESSURE CHANNELS (IEC 60041)

- Circular penstock
  - At least 13 measuring points
- Rectangular /Trapezoidal Section
  - At least 25 measuring points
- Increase measuring points if velocity distribution is non – uniform
- Consequences
  - Excessive blockage, large angle, lower accuracy, high cost of mounting frame

# DISCHARGE MEASUREMENT WITH CURRENT METERS IN OPEN CHANNELS (IEC 60041)

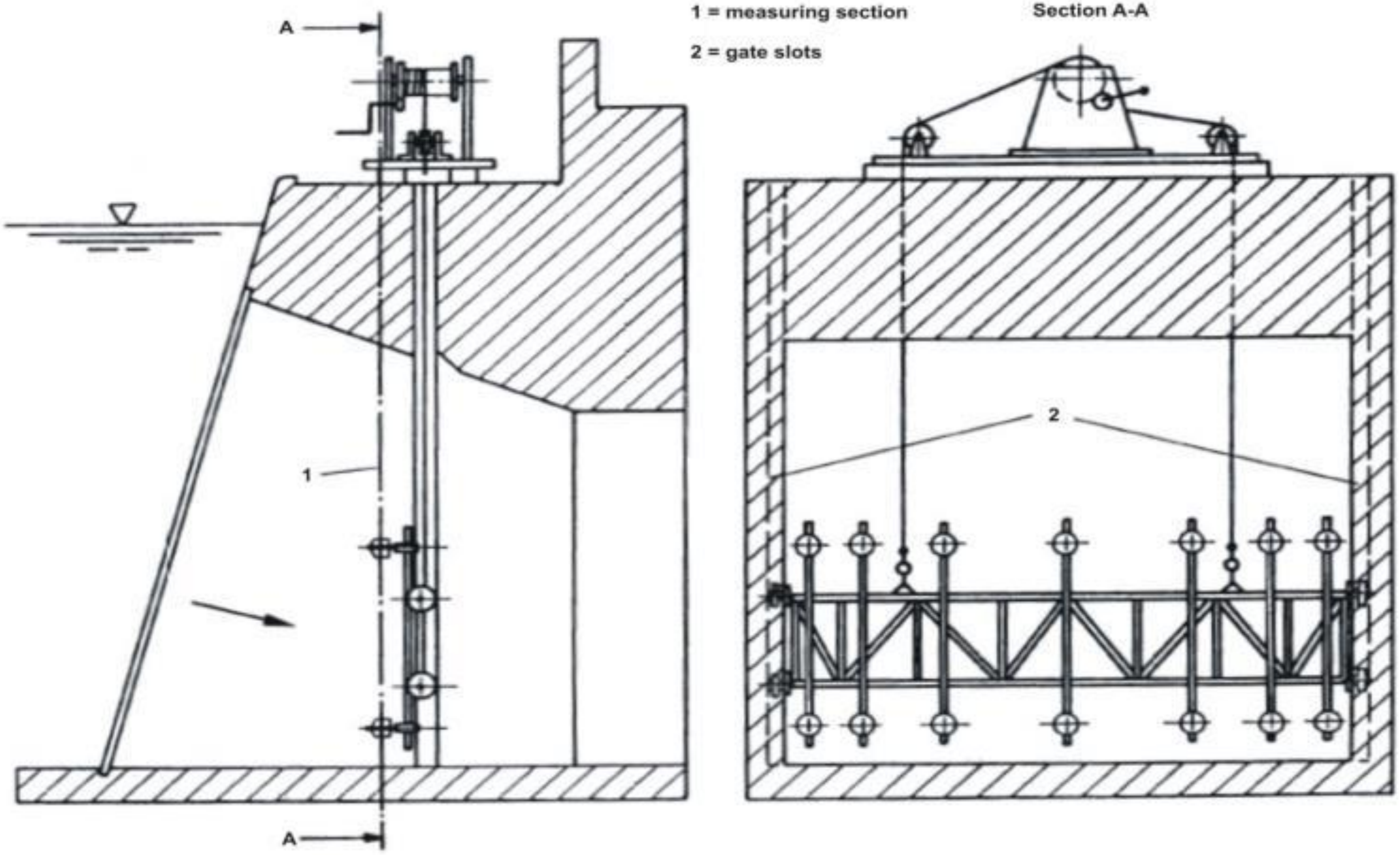
- Measuring section width & depth ≥ 0.80 m and ≥ 8 x propeller dia
- Measuring section ≥ 10 x hydraulic radius (Hydraulic Radius = wetted cross-sectional area ÷ wetted perimeter)
- Measuring points ≥ 25
- Stiff mounting structure to prevent vibrations of current meters.

# VERTICAL ROW OF CURRENT METERS ON TRAVELLING WINCH




IEC Recommendation

# HORIZONTAL ROW OF CURRENT METERS MOVED BY HOIST




IEC Recommendation

# FRAME SUPPORTING HORIZONTAL ROW OF CURRENT METERS

## Practical Implementation

(a) Frame Raised

# FRAME SUPPORTING HORIZONTAL ROW OF CURRENT METERS

Practical Implementation


(b) Frame Lowered

# ACOUSTIC METHODS OF DISCHARGE MEASUREMENT

# ACOUSTIC METHODS

- ***Transit-Time Method***

  *Ultrasonic transit-time flowmeters*

  - Wet-Transducers Type (Intrusion type)
  - Dry-Transducers Type (Clamp-on-type)

- ***Doppler-Shift Method***

  *Acoustic Doppler current profilers*

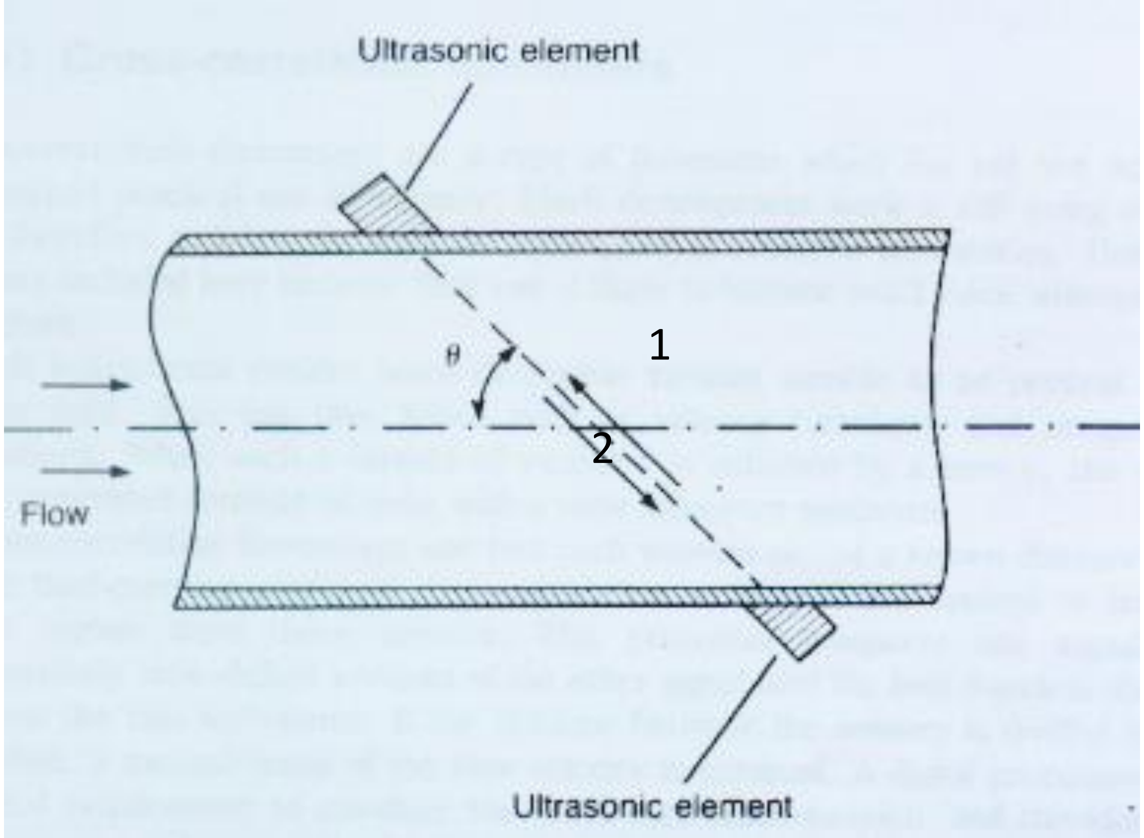
  - Horizontal-Beam ADCP
  - Vertical-Beam ADCP

# ULTRASONIC TRANSIT-TIME FLOWMETER (UTTF)

- *Based on transit-time of ultrasonic beam*
- *Suspended particles not necessary*
- *Measures average velocity along beam path*
- *Now highly preferred*
- *Not a standard procedure as per IEC-60041 but can be used subject to agreement between parties*

# ULTRASONIC TRANSIT-TIME FLOWMETER (UTTF)

## Principle




Let

c = beam velocity in water

$\nu$ = water velocity along axis of conduit

L = length of path

$t_1 = L / (c - \nu \cos\theta)$

$t_2 = L / (c + \nu \cos\theta)$

Therefore

$\Delta t = t_1 - t_2$

$= 2L\nu\cos\theta / (c^2 - \nu^2 \cos^2\theta)$

$\approx 2L\nu\cos\theta / c^2$

# DISCHARGE MEASUREMENT IN CIRCULAR CONDUITS BY CLAMP-ON TYPE UTTF

- ***Transmission mode***
  - Affected by transverse velocity component
  - Short exposed length of penstock is enough

- ***Reflection mode***
  - Not affected by transverse velocity component
  - Double exposed length of penstock is necessary

# DISCHARGE MEASUREMENT IN CIRCULAR CONDUITS BY CLAMP-ON TYPE UTTF

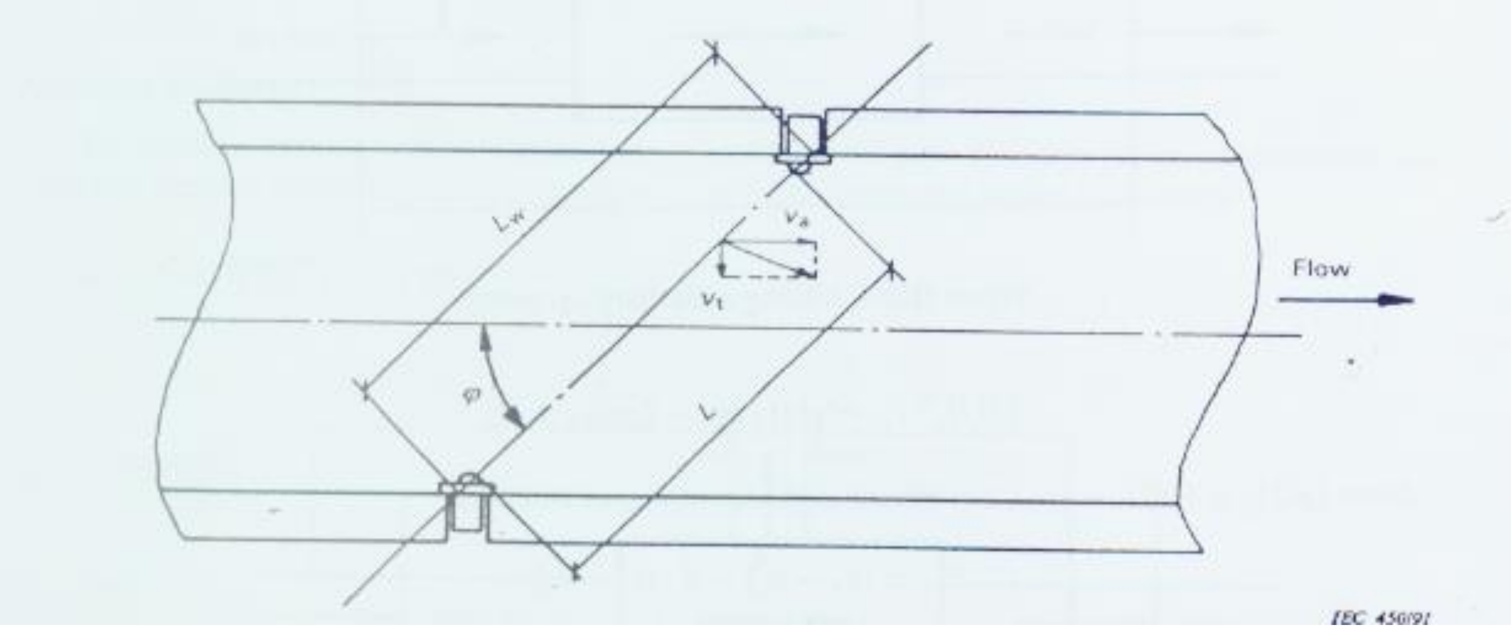
Transducers in Reflection Mode Clamped on Penstock

# DISCHARGE MEASUREMENT IN CIRCULAR CONDUITS BY INTRUSION TYPE UTTF

- Single-path method
- Two-path method
- Four-path method
- Eight-path method
- Sixteen-path method

# DISCHARGE MEASUREMENT IN CIRCULAR CONDUITS BY INTRUSION-TYPE METHOD

IEC- 60041 : Recommended Acoustic Plane




Angle between beam direction and pipe axis, $\phi = 45^{\circ}\ to\ 75^{\circ}$

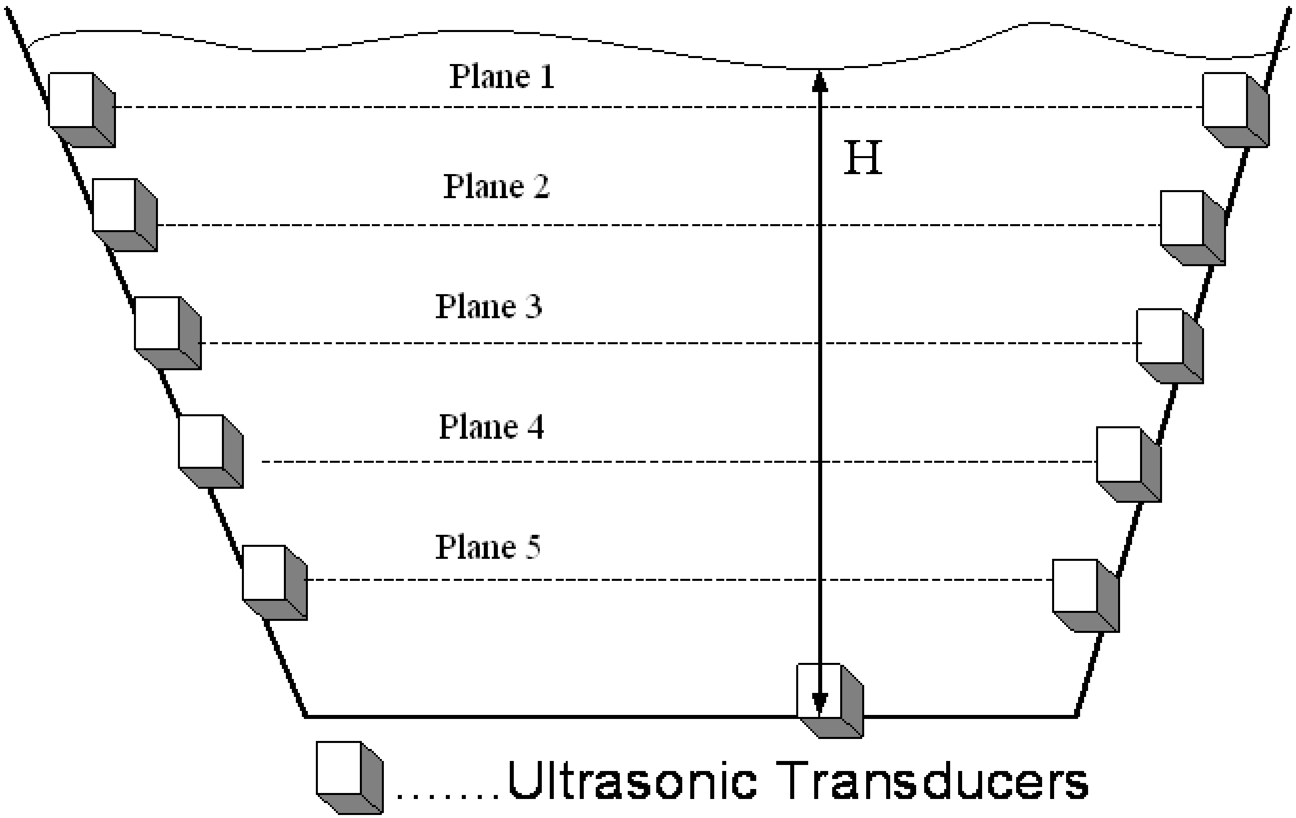
# DISCHARGE MEASUREMENT IN CIRCULAR CONDUITS BY UTTF (IEC 60041)

- Straight Length:
  - Straight length upstream ≥ 10
  - Straight length downstream ≥ 3 D
  - If short length or bend, increase no. of paths

- Exposed Length:
  - Minimum 0.6D
  - Desirable 1.5D

# DISCHARGE MEASUREMENT IN OPEN CHANNEL BY INTRUSION-TYPE UTTF

## Multi-Path Method for Open Channel



# ACOUSTIC DOPPLER CURRENT PROFILERS (ADCPs)

- Horizontal-Beam Acoustic Doppler Profiler (H-ADCP)

- Vertical-Beam Acoustic Doppler Current Profiler (V-ADCP).

- Not mentioned in IEC-60041

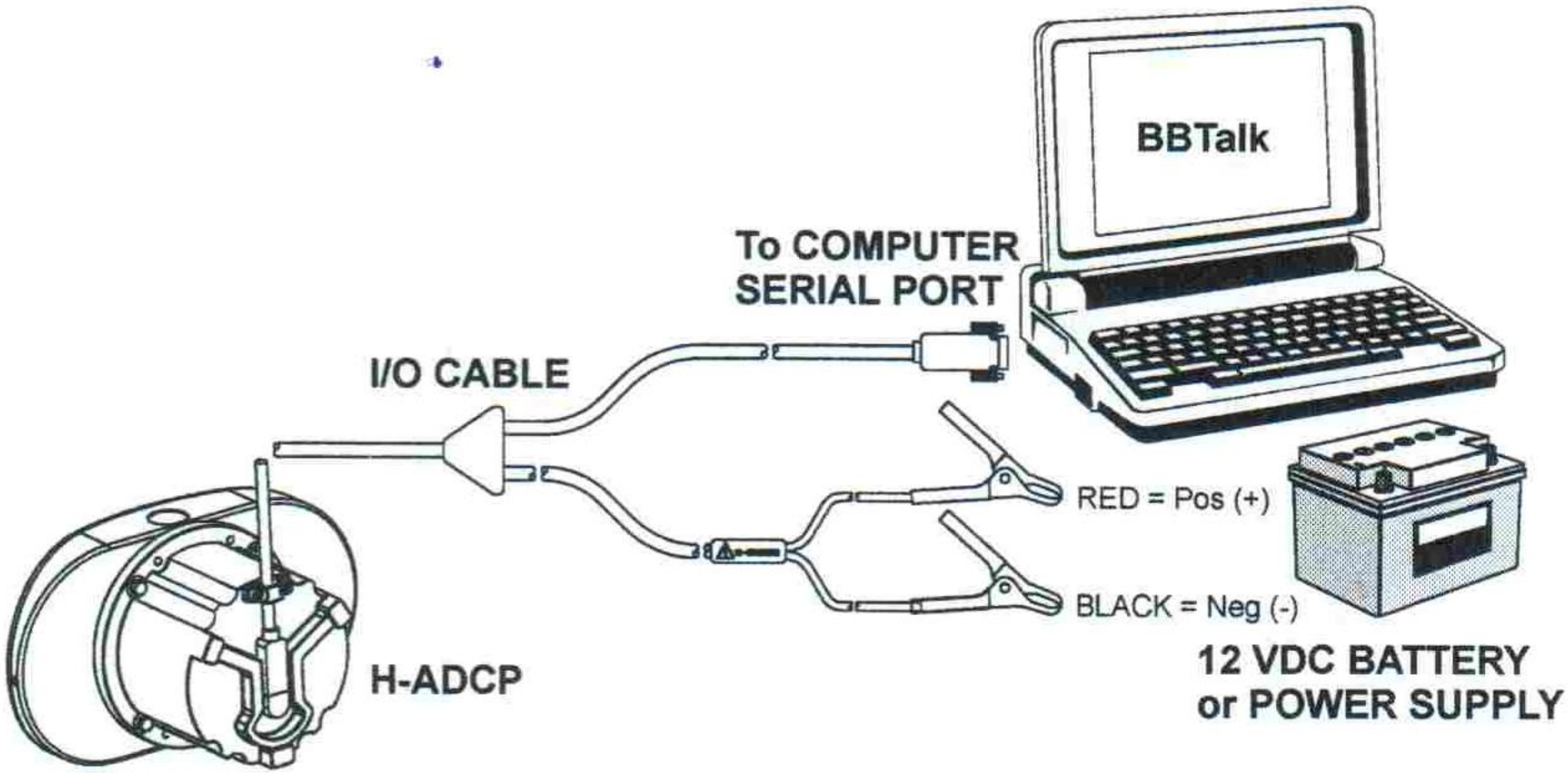
# HORIZONTAL-BEAM ADCP: HIGHLIGHTS

- Provides real-time current profile along width of channel.
- Acoustic beam of 300 kHz or higher frequency.
- Transducer is fitted with horizontal beam orientation.
- Some blank distance close to transducer.
- Channel width divided  into cells.
- Cell size is user selectable
- Sampling interval also user selectable.
- Output data transferred on-line to a PC
- Data transfer to PC by software bundled with instrument.
- Data is processed and profile is generated by PC.
- Profile displayed graphically
- Profile also available as data file.
- Discharge calculation by software bundled with instrument or own software.

# HORIZONTAL-BEAM ADCP: TRANSDUCER HEAD

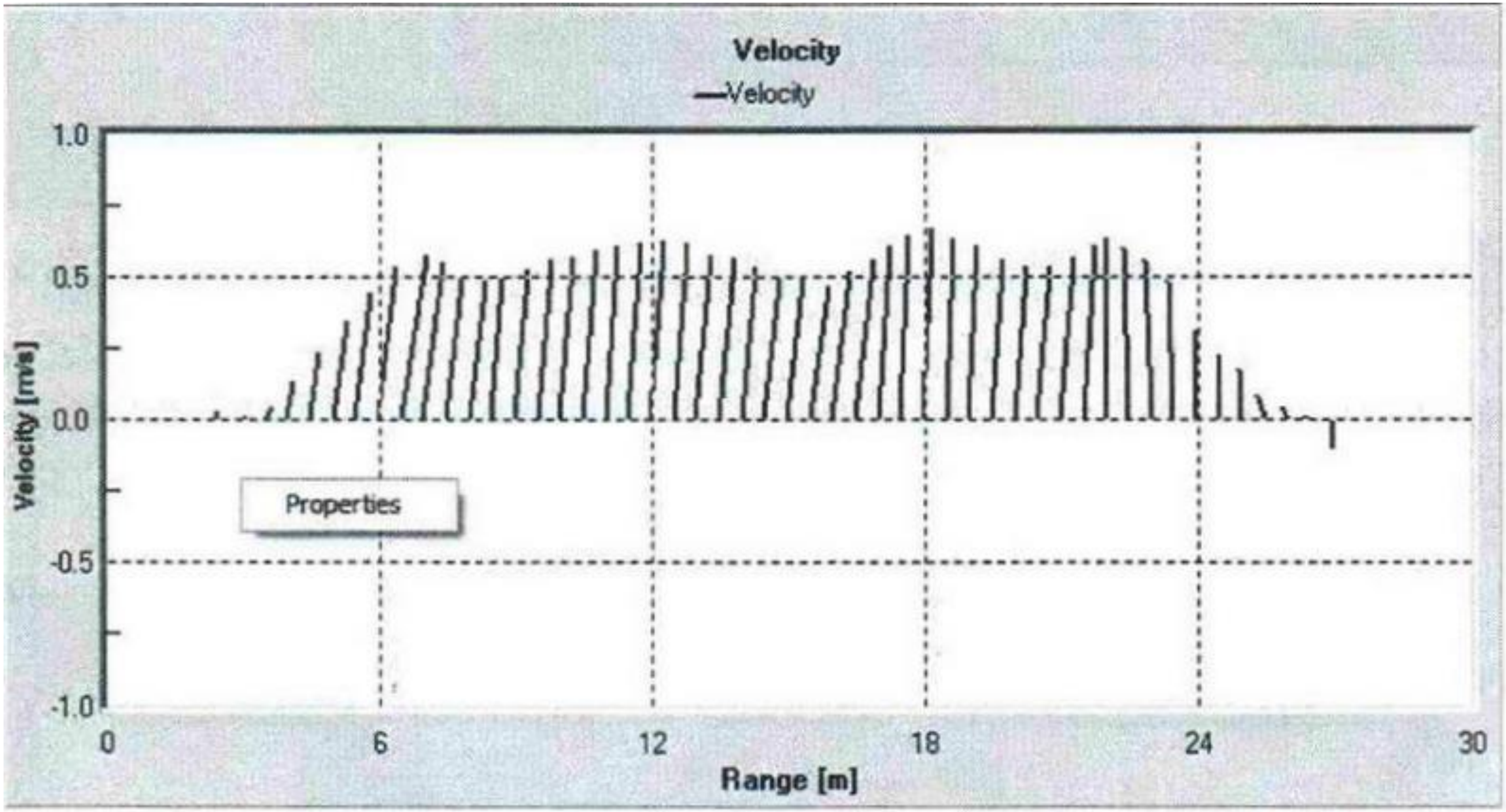

Source: RD Instruments Manual

# HORIZONTAL - BEAM ADCP: SETUP




Source: RD Instruments Manual

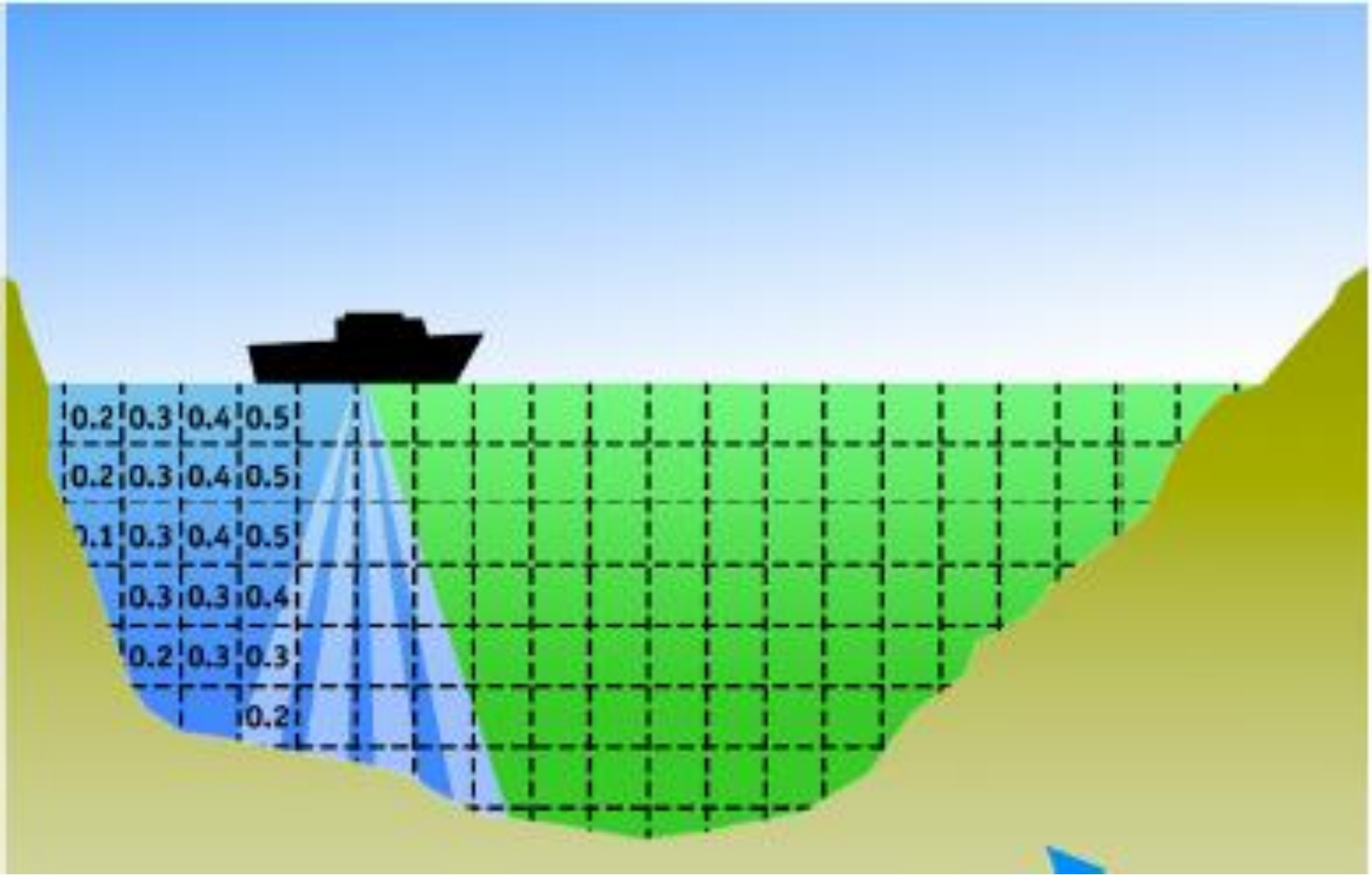
# HORIZONTAL-BEAM ADCP: CURRENT STICKS




Source: RD Instruments Manual

# MANEUVERING H-ADCP ON GUIDE-RAIL

# VERTICAL-BEAM ADCP: BEAMS AND CELLS




Source: RD Instruments Manual

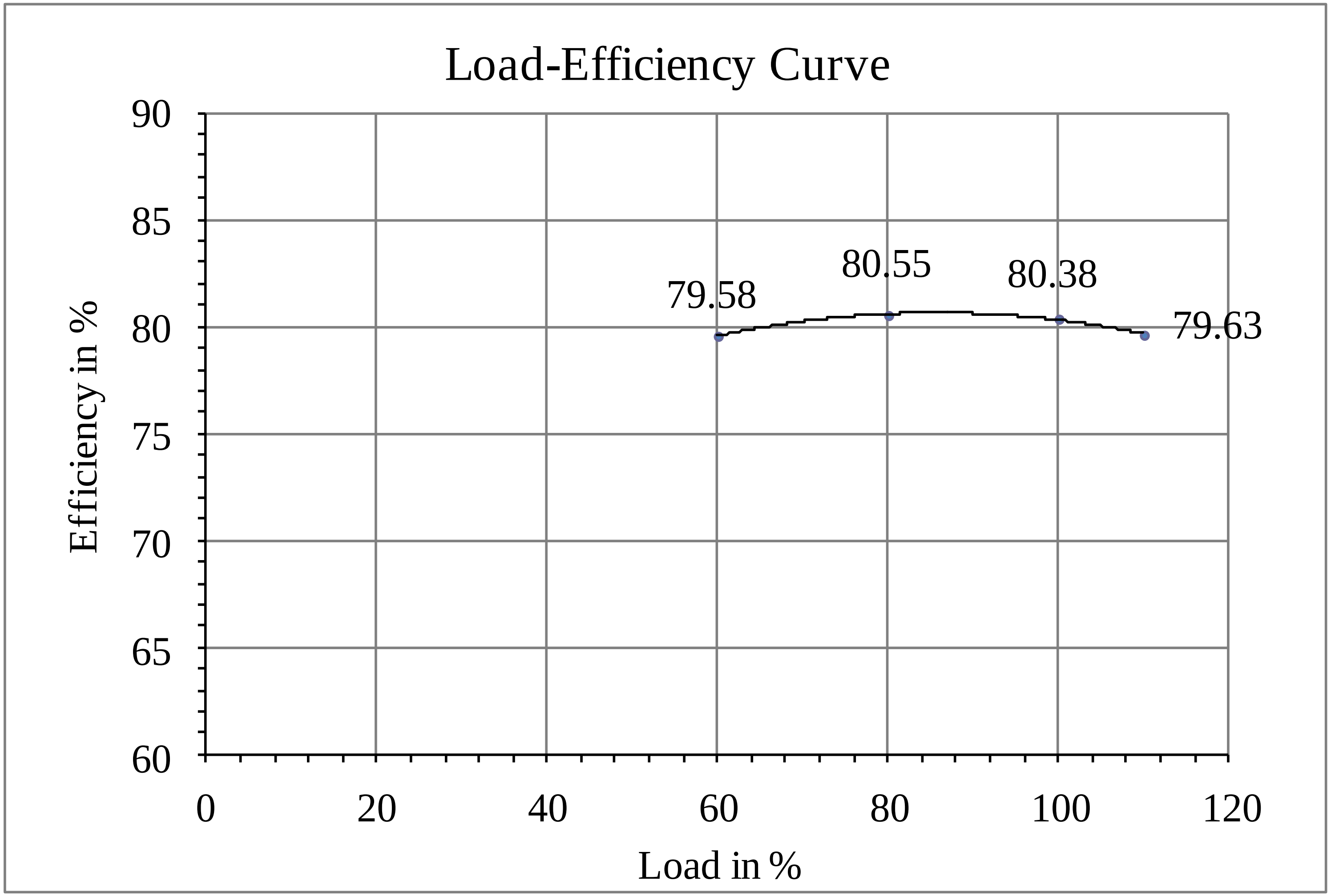
# VERTICAL-BEAM ADCP: MOUNTING BOAT

Source: RD Instruments Manual

# MANEUVERING V-ADCP BOAT FROM BANKS

**The most important and critical tests to be conducted under performance testing are:**

- Maximum Power Output Test
- Unit Efficiency Test
- Index Test

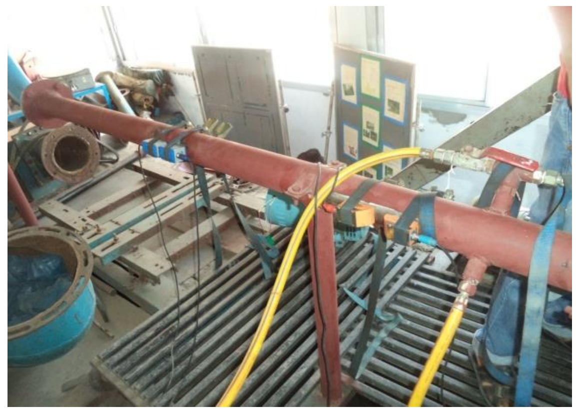

Load-Efficiency Curve
90
85
80
75
70
65
60
79.58
80.55
80.38
79.63
0
20
40
60
80
100
120
Efficiency in %
Load in %

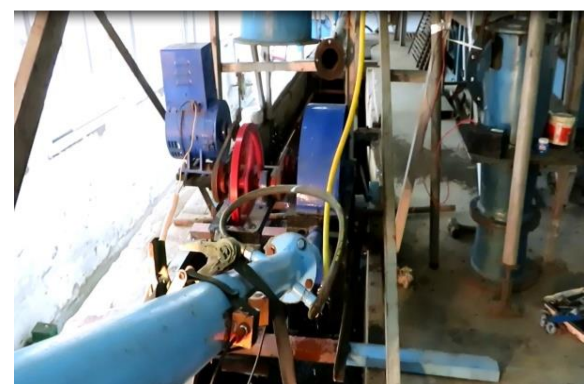
# TURBINE – GENERATOR UNIT

## General Health

- Temperature rise, sound level and vibration levels are the good indicators of the general health of any machine.
- The following measurements are carried out on each generating unit, subject to the accessibility of the relevant part for fixing sensor(s):
  - Temperature rise of bearing oil
  - Sound level
  - Bearing vibrations
  - Shaft vibrations

# TURBINE TESTING LABORATORY

# TURBINE TESTING LABORATORY

# IMPROVED WATERMILLS/TURBINES TESTED AT HRED, IIT ROORKEE

Gita Flow Pumps India Pvt. Ltd., Saharanpur

Standard Electronics Instruments Roorkee

DRG Jalshakti Engineering, Kolkata

SBA Hydro Systems Pvt. Ltd., New Delhi

M/s Gopal Engineering Works, Almora, Uttarakhand

M/s Mir Engineering Works, Almora, Uttarakhand

M/s Azad Engineering Co., Ghaziabad, UP

M/s Mandakini Water Power Sytem, Rudraprayag

M/s Ushamil Pvt. Ltd., New Delhi

M/s Expert Watermill Workshop, Dehradun

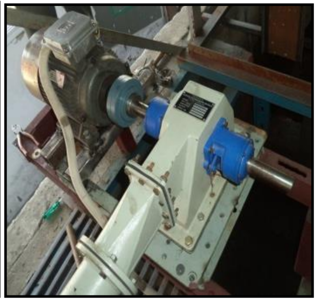
M/s Himalayan Gramodhyog Lokseva Sansthan, Dehradun

M/s Chitwal Kisan Vikas Samiti, Pauri

M/s Dobriyal Brothers Kotdwara, Pauri Garhwal

M/s Deewan Singh Dhobi Ghat, Piana, Pithoragarh

M/s Prakruti Hydro Labs, Yelachenahalli, Bangalore



M/s Naveen Engineering Works, Kalanagar, West, Bangalore

M/s CERES, NEPeD, Kohima, Nagaland

M/s National Industrial Training & Consultancy (NITCO), Jammu, J&K

M/s Rahmat Khan, NTD, Almora, Uttarakhand

Nu-Ex Techno Cluster Santoshpur,Kolkata

# LIST OF IMPROVED WATERMILLS/ TURBINES TESTED BY HRED, IIT ROORKEE

| S. No. | Name of Manufacturer/ Supplier | Type of water mill | Type of runner |
|---|---|---|---|
| 1. | M/s Gita Flopumps India Pvt. Ltd., Saharanpur, U.P. | Horizontal shaft | Cross flow |
| 2. | M/s Standard Electronic Instruments Corpn., Roorkee Uttarakhand | Horizontal shaft | Cross flow (open type) |
| 3. | M/s SBA Hydro Systems (Pvt) Ltd., New Delhi | Horizontal shaft | Cross flow |
| 4. | M/s Gopal Engineering Works, Dharanaula, Almora Uttarakhand | Horizontal shaft | Cross flow |
| 5. | M/s DRG Jalshakti Engineering, Kolkata | Horizontal shaft | Cross flow |
| 6. | M/s Mir Engineering and Builders, Srinagar, J&K. | Horizontal shaft | Cross flow |
| 7. | M/s Mandakini Water Power System, Patti-Purvi Bangar, Distt.-Rudraprayag | Horizontal shaft | Pelton type |
| 8. | M/s Expert Watermill Establishment Workshop, Lachhiwala, Dehradun Uttarakhand | Vertical shaft | Impulse type |
| 9. | M/s Himalayan Gramodhyog, Lok Seva Sansthan, VPO- Nathwa Wala, Dehradun | Vertical shaft | Impulse type |
| 10. | M/s Ushmil Hydro Systems (P) Ltd, New Delhi | Vertical shaft | Propeller type |
| 11. | M/s Chitwal Kisan Vikas Samiti., Patti-Chauthan, Pauri Garhwal Uttarakhand | Vertical shaft | Pelton type |
| 12. | M/s Azad Engineering Co., Industrial Area,Ghaziabad, U.P. | Horizontal shaft | Cross flow |
| 13. | M/s Mahesh Micros & Electricals, Gyansu, Uttarkashi, Uttarakhand | Vertical Shaft | Semi-Turgo Impulse |
| 14. | M/s National Industrial Training & Consultancy (NITCO), Jammu, J&K | Horizontal Shaft | Cross Flow |
| 15. | M/s Rahmat Khan, NTD, Almora, Uttarakhand | Horizontal Shaft | Cross Flow |
| 16. | M/s Deewan Singh (Contractor), Dhobi Ghat, Piana, Pithoragarh (Uttarakhand) | Horizontal Shaft | Cross Flow |
| 17. | M/s Dobriyal Brothers, Devi Road, Kotdwara District Pauri Garhwal (Uttarakhand) | Horizontal Shaft | Cross Flow |
| 18. | M/s Mahesh Micros & Electricals, Gyanshu, Uttarkashi (Uttarakhand) | Horizontal Shaft | Cross Flow |
| 19. | M/s Prakruti Hydro Labs, Yelachenahalli, Bangalore | Horizontal Shaft | Pelton |
| 20. | M/s CERES, NEPeD, Kohima, Nagaland | Horizontal Shaft | Turgo |
| 21. | Naveen Engineering Works, Jalahalli West, Bangalore | Horizontal Shaft | Cross Flow |
| 22. | M/s Jayanti Bhai P. Patel, Thaltej, Ahmedabad | Horizontal | Undershot Wheel |
| 23. | National Innovation Foundation India, Satellite, Ahmedabad | Horizontal (I-1kW) | Impulse Turbine |
| 24. | National Innovation Foundation India, Satellite, Ahmedabad | Horizontal (II-2kW) | Impulse Turbine |
| 25. | Nu-Ex Techno Cluster, Kalibari Road, Santoshpur, Kolkata | Horizontal | |

Thank you