SITE CALIBRATION OF RADAR TYPE ULTRASONIC FLOWMETER USING ADCP

P.M. Abdul Rahiman* N.P. Khaparde K. Kumar B. Suresh Kumar S. Sampath

*Central Water and Power Research Station (CWPRS), Pune-24, *rah4uin@yahoo.co.in*

ABSTRACT

Custody transfer of water is a critical issue when water is considered as valuable resources serving the needs of domestic and industrial purposes. The measurement of flow rate by primary and secondary method plays a vital role for the effective utilization of available resources. The issue aggravated especially when the custody is at dispute becomes between two governmental bodies. Such a critical issue has been encountered by Delhi Jal Board (DJB) for measuring drinking water flow through open canal.

The continuous discharge through open canals for New Delhi drinking water supply was measured using the non-contact radar type sensors on the principle of Doppler effect. The measuring system was well equipped with SCADA based continuous monitoring arrangement. It was difficult to dismantle and ship the instrument for the purpose of calibration using primary standard in a laboratory. Hence, site calibration was carried out using advanced Acoustic Doppler Current Profiler (ADCP) and conventional current meters. The secondary wet calibration was carried out at site at varied flow ranges using ADCP and was also re-verified with conventional current meters according to BIS standards 1192:1981 and ISO 748:1997. The results were found to be within ± 2 percent of the acceptance limits.

Keywords: ADCP, current meter, canal, radar, flowmeter, ultrasonic , calibration

1. INTRODUCTION

The measurement of flow rate is very significant for effective utilization of available source of water. In addition, it is important to measure the flow rate accurately during custody transfer or process control applications. In this context, many water utilities are looking forward to streamline the water consumption pattern through precise measurement, water auditing calls for consequent improvement in the system. During the custody transfer, it is always advised to use best suitable metering arrangement to ensure accurate flow measurement.

There are numerous techniques for measuring flow rates in open channels and closed conduits. Measurement of local velocities within a gauging section is one scenario in which conventional rotating element type of water current meters are mostly used for velocity measurements. Non rotating element types like Electromagnetic, ADCP, Self Recording type and Contact Free Radar type meter which contain no rotating parts, are also used for measuring the flow measurements in rivers, open channel and oceanography. The exact and real-time knowledge of the discharge is an important task in the field of hydrology, water storage and management, irrigation and hydro electric power plants.

2. DESCRIPTION OF FLOW MONITORING AT SITE

DJB is responsible for the supply of potable water in Delhi and its distribution in the area under the control of Municipal Corporation of Delhi. The DJB also supplies water in bulk to New Delhi Municipal Corporation (NDMC) and Delhi Cantonment. Besides, the Board is responsible for collection, treatment and disposal of sewage in Delhi. To make up the shortage, DJB took recourse to a number of schemes like recycling of waste water at Water Treatment Plants, optimization of water usage and rain water harvesting and conservation of water etc. For the effective utilization of available resources and for custody transfer, DJB has acquired and commissioned a pair of contact free radar type discharge measurement sensors of Make: Sommer Messtechnik, GmbH, Austria to measure the continuous river flow velocity in Carrier Lined Canal (CLC) and Delhi Sub Branch (DSB) of DJB. The flow meter is embedded with a state of art mobile commuting and data transmission facility in order to update flow data to various the stakeholders. The data acquired by the system is transmitted to the user end periodically (generally on hourly basis), that can be monitored and analysed for the benefit of user. Thus the flow metering system is well secured and transparent.

Government of NCT of Delhi through DJB had initiated and apprised CWPRS to undertake studies on Calibration/Testing of Open channel Ultrasonic Non Insertion type Flow meters installed at the sites of CLC and DSB catering to Heiderpur water treatment plant. As an outcome, a team of officials from CWPRS visited the site during the first week of Feb 2016 for calibration of existing Non – contact type flow meters by secondary flow measurement techniques of ADCP and propeller type current meters. It was initially suggested by CWPRS, to carry out such a calibration exercise by shipping the measuring equipment for calibration in 2 m^3/s gravimetric calibration laboratory. However, they insisted that they have exhausted many options available and finally approached CWPRS for undertaking this calibration work considering the expertise of CWPRS in this area. Field data collections were carried out after the initial discussion with the officials of DJB.

3. SALIENT FEATURES OF WATER SUPPLY SCHEME

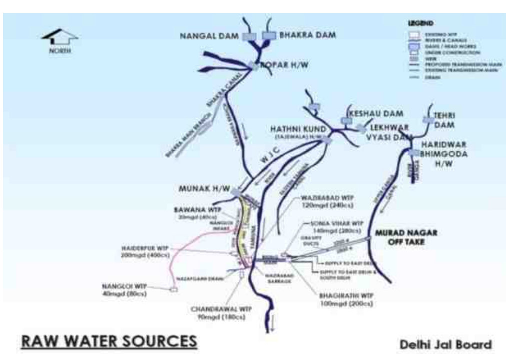

Figure 1 Raw water scheme of DJB

Supplying water to metro cities like Delhi is a big challenge for Delhi Jal Board. This has acquired importance such as owning one of the largest water treatment plants in Asia with a capacity of 1000 cusecs.

The salient features of the water scheme are:

- Delhi and Haryana entered in to a Memorandum of Understanding (MOU) in 1993 for construction of CLC from Munak Head Regulator to Haiderpur WTP, parallel to the existing unlined Delhi Sub-Branch of Western Jamuna Canal (WJC).
- The objective of construction of CLC in a length of 102 KM was to provide alternate conveyance system for maintenance of the existing unlined canal and to reduce en-route seepage losses from 30% to 5%.
- CLC with capacity of 723 cusecs and costing Rs. 520 crore has been funded by Delhi.

The schematic view of the raw water sources of DJB is shown in Figure 1.

4. FLOW MEASUREMENT ARRANGEMENT AT SITE

DJB had acquired contact free radar type discharge sensors manufactured by Sommer Messtechnik, GmbH, Austria to measure the continuous river flow velocities which are equipped with sophisticated and advanced technology.

4.1 Principle of Measurement for Contact Free Radar Sensor

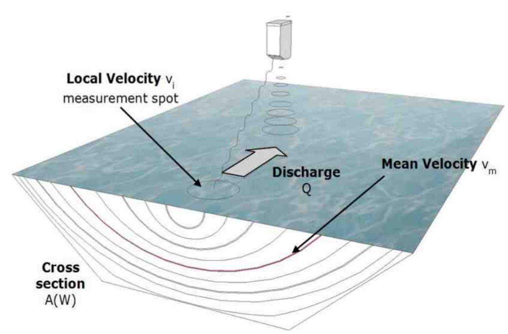

Figure 2 Principle of RQ30A sensor

The RQ30A contact free radar sensor measures the flow velocity and water level at the water surface. Figure 2 shows the schematic view for discharge measurement principle of RQ30A radar sensor.

The contact-free measurement of the flow velocity is based on the principle of the Doppler Effect. The radar sensor transmits a signal with a constant frequency in a specific angle to the water surface. Then the signal is reflected back. Due to fluid movement, a shift in frequency is observed. This shift in frequency is linearly proportional to the velocity of moving fluid. The reflected signal is received by the antenna of the radar sensor. Thus by comparing the transmitted frequency to the frequency of the reflected signal from the water surface the local velocity can be determined.

4.2 Radar spectrum

The radar sensor has an opening angle of 12°. Therefore the signals of an area are measured. The size of the area depends on the inclination angle and the distance from the sensor to the reflecting water surface. The velocities appearing in this area have a specific distribution depending on the current conditions. The velocity distribution is determined with a digital signal processor using spectral analysis and the dominant velocity in the measurement area is calculated. Spectra can be output and used to evaluate measurements at gauging sites.

4.3 Separation of direction

Movements can appear in directions either towards or away from the radar sensor. Depending on the direction a frequency shift to higher or lower frequencies occurs. This phenomenon allows the radar sensor to distinguish the flow directions and accordingly evaluate the velocity distribution.

4.4 Inclination angle measurement

As the radar sensor is directed in a specific angle to the water surface an angle correction has to be applied. The radar sensor internally measures its vertical inclination and uses this value for automatic angle correction.

4.5 Principle of Water Level measurement

The water level is measured employing contact-free method, using the principle of transit time measurements of reflected signals. The radar sensor is installed above a river and transmits a short micro wave impulse in the direction of the water surface. This impulse is reflected from the water surface and is recorded by the same sensor now working as receiver. The time between transmitting and receiving the impulse is directly proportional to the distance from sensor to water surface.

5. THE CONTACT FREE RADAR SENSOR

Theses contact free radar sensors are RQ30A type and manufactured by Sommer Messtechnik GmbH, Austria. A detailed specification of radar sensor for velocity measurement and water level measurement sensor is given in Table 1 & 2.

Table 1 - Specification of radar sensor for Velocity measurement

Detectable measurement range	0.10…15 m/s
Accuracy	± 0.02 m/s
Resolution	1 mm/s
Recognition of direction	+/-
Measurement duration	5…240 s
Measurement interval	8 s…5 h
Measurement frequency	24 GHz (K-Band)
Radar opening angle	12 °
Distance to water surface	0.50…35 m
Vertical inclination	measured internally

Figure 3 shows a typical view of contact free radar sensor with its support structure at the site of CLC along with flow measurement using ADCP.

Table 2 - Specification of radar sensor for Water level measurement

Measurement range (from radar transmitter to water surface)	0…15 m (0…49.21 ft.) 0…35 m (0…114.83 ft.)
Resolution	1 mm
Accuracy	± 2 mm; ± 0.025 % FS (15 m)
Radar frequency	26 GHz (K-Band)
Radar opening angle	10 °

Figure 3 Contact free radar sensor being calibrated with ADCP

6. COMPUTATION OF DISCHARGE

Figure 4 A view of propeller type current meter

Current meters used for velocity measurement at site are of Propeller type horizontal axis current meter. The current meter of make Valeport is pre-calibrated in CWPRS current meter rating facility with an acceptable accuracy. A Digital Echo Sounder is used for measuring the respective depth of the sections. Figure 4 & 5 show the Propeller type current meter and the Echo Sounder.

Figure 5 A view of digital echo sounder

Initially, the cross sections of the canals are physically measured using conventional methods. The measured sections of CLC and DSB at a given time during the field studies are shown in Figures 6 and 7.

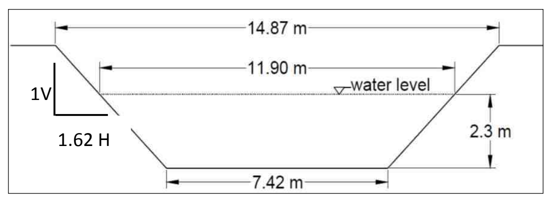

Figure 6 Cross section of CLC

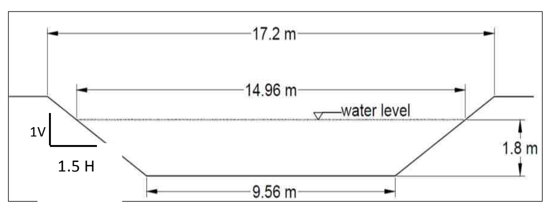

Figure 7 Cross section of DSB

6.1 Velocity measurement methodology

The current meter is placed below the water surface at relative water depths of 0.2, 0.6 & 0.8 of water depth and a velocity measurement is made. Generally, three point method is used when the velocities in the verticals appear to be abnormally distributed such as having an unusual velocity distribution. The three point method combines both two point method and the

Six-Tenth depth method. Therefore, current meter measurement are taken at 0.2, 0.6 and 0.8 of the flow depth. The mean velocity in the verticals is obtained by first averaging the velocity measurement at 0.2, 0.8 of the flow depth (Two Point method). Then averaging the result with the velocity measured at 0.6 of the depth. Thus, the mean velocity in the vertical would be

$$\bar{V} = \frac{\frac{(V_{0.2}+V_{0.8})}{2} + V_{0.6}}{2}$$

A current meter measurement is the summation of the products of the subsection areas of the stream cross-section and their respective average velocities. The continuity equation is used

$$q = a * v$$

$$Q = \sum_{1}^{n} (a * v)$$

Where,

q - Discharge from an individual section
a - Individual section area
v - Mean velocity of the flow normal to the section and
Q -Discharge from the cross-section

6.2 Mid-Section Method

In the Mid-section method of computing a current meter measurement, it is assumed that the velocity sample at each vertical represents the mean velocity in a rectangular subsection. The subsection area extends laterally from half the distance from the preceding observation vertical to half the distance to the next, and the vertical from the water surface to the sounded depth. The cross section is defined by depths at verticals 1,2,3,4....n.

The discharge passing through each segment was worked out using mid section method as explained in BIS 1192: 1981 and ISO 748: 1997. Total discharge in the canal was then obtained by adding all the segment discharges. The discharge data observed during the visit is given in Table 4.

6.3 Discharge Measurements using ADCP

The ADCP is an acoustic instrument designed to measure discharges in river/canal, three dimensional water currents, depths and bathymetry from a moving or stationary vessel. Water-velocity measurements are made by transmitting sound at a known frequency into the water and measuring the Doppler shift, or change in sound frequency, from signals reflected off particles in the water.

Table 3 - Features of ADCP

Profiling Range — Distance	0.06 to 40 m
Profiling Range – Velocity	±20 m/s
Velocity — Accuracy	±0.25% of measured velocity ±0.2 cm/s
Velocity — Resolution	0.001 m/s
Number of Cells	Up to 128
Cell Size	0.02 to 4 m
Transducer Configuration	Nine (9) Transducers
	Dual 4-beam 3.0 MHz/1.0 MHz Janus 25° Slant Angle
	0.5 MHz Vertical Beam Echosounder
Depth — Range	0.20 to 80 m
Depth — Accuracy	1%
Depth — Resolution	0.001 m
Discharge Measurement Range — Bottom-Track	0.3 to 40 m
Discharge Measurement Range — RTK GPS	0.3 to 80 m
Discharge Measurement — Computations	Internal
Bluetooth Range	Up to 200 m

The primary advantages of making discharge measurements using the ADCP as compared with point velocity meters, such as the current meter are that, the time required to complete a measurement is reduced, the ADCP allows for data to be collected throughout most of the water column and cross section rather than at discrete points, the ADCP is deployed at the water surface appreciably reducing the chance of snagging by debris, the instrument can be boat-mounted thus, eliminating the installation, maintenance, and liability of costly manned cableways/cradle arrangement.The features of ADCP flow measuring equipment are shown in Table 3.

The main external components of an ADCP are a transducer assembly and a pressure case. The transducer assembly consists of nine transducers that operate at a fixed, ultrasonic frequency, typically Dual 4-beam 3.0 MHz/1.0 MHz, Janus 25° slant Angle, 0.5 MHz Vertical Beam Echo sounder. The pressure case is attached to the transducer assembly and contains most of the instrument electronics. When an ADCP is deployed from a moving boat, it is connected by bluetooth to a portable laptop. The computer is used to program the instrument, monitor its operation, and collect and store the data.

The ADCP measures velocity magnitude and direction using the Doppler shift of acoustic energy reflected by material suspended in the water column. The ADCP transmits pairs of short acoustic pulses along a narrow beam from each of the four transducers. As the pulses travel through the water column, they strike suspended sediment and organic particles (referred to as “scatterers”) that reflect some of the acoustic energy back to the ADCP. The ADCP receives and records the reflected pulses. The reflected pulses are separated by time differences into successive, uniformly spaced volumes called “depth cells”. The frequency shift (known as the “Doppler effect”) and the time-lag change between successive reflected pulses are proportional to the velocity of the scatterers relative to the ADCP. The ADCP computes a velocity component along each beam; because the beams are positioned orthogonally to one another and at a known angle from the vertical (usually 20 or 30 degrees), trigonometric relations are used to compute three-dimensional water-velocity vectors for each depth cell. Thus, the ADCP produces vertical velocity profiles composed of water speeds and directions at regularly spaced intervals.

ADCP discharge measurements are made from moving boats; therefore, the boat velocities must be subtracted from the ADCP measured water velocities. ADCP’s can compute the boat speed and direction using “bottom tracking” (RD Instruments, 1989). The channel bottom is tracked by measuring the Doppler shift of acoustic pulses reflected from the bottom to measure boat speed; direction is determined with the ADCP on-board compass. If the channel bottom is stationary, this technique accurately measures the velocity and direction of the boat. The bottom-track echoes also are used to estimate the depth of the river (Oberg, 1994).

ADCP discharge measurements are made by moving the ADCP across the channel while it collects vertical- velocity profile and channel-depth data. The ADCP transmits acoustic pulses into the water column. The groups of pulses include water-profiling pulses and bottom-tracking pulses. A group of pulses containing an operator-set number of water-profiling pulses (or water pings) interspersed with an operator-set number of bottom- tracking pulses (or bottom pings) is an “ensemble”; a single ensemble may be compared to a single vertical from a conventional discharge measurement (Oberg, 1994). A single crossing of the stream from one side to the other is referred to as a “transect.” Each transect normally contains many ensembles. When depth and water velocities are known for each ensemble, an ADCP can compute the discharge for each ensemble. The discharge from all transect ensembles are summed, yielding a computation of river discharge for the entire transect. ADCP operational parameters (such as depth-cell length, number of water and bottom pings per ensemble, and time between pings) are set by the instrument user. The settings for these parameters are governed by canal/river conditions (such as depth and water speed) and also by the frequency and physical configuration of the ADCP unit (RD Instruments, 1989).

6.4 Measurement Procedure using ADCP

The Hydro boat carrying the ADCP is traversed from one end to the other end of the canal across the section. The measurement of discharge using the river surveyor system comprises of three components viz., Start Edge, Transect and End Edge. ADCP calculates the total discharge by summing the Start Edge, Top Estimate, Measured Area, Bottom Estimate and End Edge. Only the Measured Area is calculated by ADCP and all other areas are calculated by a technique known as Velocity Profile Extrapolation using power law velocity profile, which is inbuilt in the software. At least four cycles of measurements are taken by ADCP for each gauge observation and the average of four measurements are computed during data processing. Likewise for different gauges the procedure is repeated and the observations are tabulated, the measurement observation using ADCP at the gauging site is shown in Figure 6. An insight of the pixel data across the canal is shown in Figure 9.

Figure 8 ADCP arrangement at site

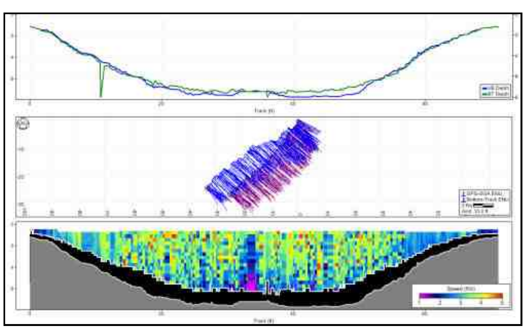

Figure 9 Pixel data of ADCP

7. RESULTS AND DISCUSSION:

Bulk data on discharge is transmitted from RQ30A radar and received by the DJB engineer for every 5 minutes. Thus entire data acquired by this sensor is analysed by CWPRS officers and average was found out for the entire 6 hours duration (12:00 – 18:00). The observation made at the site on 2nd and 3rd February 2016 and reference fluctuations by ADCP and current meter are presented in Table 4 below. In this case of CLC, there was wide variation of +8.649% to +7.226% where as it is lying between +5.640% to +4.469% with respect to current meter readings. Between these errors, their variation is within 2%. In the case of DSB, the variation is within -0.203% to -1.259 %. When compared with errors in current meter readings vary from -0.966% to -6.489%, which is also an encouraging value of accuracy. The RQ30A radar sensors exhibited accurate flow measurement system.

Table 4 - Results of CLC

Date	Q_m (ft/sec)	Q_{ADCP} (ft/sec)	Q_c (ft/sec)	$\%_{ADCP}$	$\%_C$
02 Feb 2016	686.663	632	650	+8.649	+5.640
03 Feb 2016	682.188	635	653	+7.226	+4.469

Table 5 - Results of DSB

Date	Q_m (ft/sec)	Q_{ADCP} (ft/sec)	Q_c (ft/sec)	$\%_{ADCP}$	$\%_C$
02 Feb 2016	388.212	389.0	392	-0.203	-0.966
03 Feb 2016	361.885	366.5	387	-1.259	-6.489

The contact free sensors, measure the velocity of flowing water from distant place. The difference may be due to the wind flow, water currents, sediment deposition, aquatic growth, rapids and falls etc. Further, the reach of the gauging section at DSB canal is irregular, which also contributes to the difference in the flow readings. The sediment depositions may also affect the readings of the flowmeter. The sediment deposition at gauging sections must be regularly cleared and the actual profile of the sediment deposition is to be measured in order to incorporate the correction factor in the flow readings. From the flow investigations carried out, it is found that the arrangement for the flow measurement at site is accurate and acceptable.

8. CONCLUSION

Field Flow measurements have been carried out at Carrier Lined Channel and Delhi Sub- Branch of Delhi Jal Board, Delhi by secondary methods. ADCP and current meters were employed to measure the flow through the canals. The results were compared with the registered data of RQ30A which are installed at gauging section of CLC and DSB canals, that being continuously transmit for monitoring at DJB end. The difference of +7 to +9 % has been observed for the non contact sensors of CLC and of – 2 % for DSB with respect to flow discharge measured by ADCP sensors. This difference is well within the acceptable range.

ACKOWLEDGEMENT

Authors express deep sense of gratitude to Dr (Mrs) V V Bhosekar, Director, CWPRS for constant encouragement and valuable suggestions during the course of the field tests. Authors also express their sincere gratitude to Shri T Nagendra, Scientist 'E' for his support in publication of this paper.

NOMENCLATURE

Q_m - Average Discharge of radar sensor at site (ft/sec)

Q_{ADCP} - Discharge measured by CWPRS using ADCP (ft/sec)

Q_c - Discharge measured by CWPRS using Current meter (ft/sec)

$\%_{ADCP}$ - Percentage error wrt ADCP

$\%_C$ - Percentage error wrt Current meter

REFERENCES

[1] BIS 1192: 1981, "Velocity area methods for measurement of flow in open channels".

[2] ISO 748: 1997, "Measurement of liquid flow in open channels – Velocity are methods"

[3] Chen YC, Chiu CL (2002) An efficient method of discharge measurement in tidal streams. J Hydrol 265(1– 4):212–224

[4] Nihei, Y., Irokawa, Y., Ide, K., and Takamura, T. (2008) "Study on River-Discharge Measurements using Accoustic Doppler Current Profilers", Journal of Hydraulic, Coastal and Environmental Engineering, vol.64, No.2, pp.99-114.

[5] Oberg, K.A., and Schmidt, A.R., 1994, Measurements of leakage from Lake Michigan through three control structures near Chicago, Illinois, April–October 1993: U.S. Geological Survey Water-Resources Investigations Report 94-4112, 48 p.

[6] Operational Hydrology Report No. 13; WMO - No. 519, World Meteorological rganization,Geneva.

[7] Sauer, V. B. and R. W. Meyer, Determination of error individual discharge measurements, U.S. Geol. Survey.

[8] Teledyne RD Instruments (2006) "Acoustic Doppler Current Profiler Principles of Operation a Practical Primer".

[9] WMO 1980 Manual on Stream Gauging. Vol I, Fieldwork. Vol II, Computation of Discharge.

[10] Technical Report No 5348, January 2016, CWPRS, Pune