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MODERN FLOW METER AND APPLICATION TO PAKISTAN IRRIGATION SYSTEM

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ABSTRACT

The accurate observations and recording of discharges of the supplies available in the rivers and those withdrawn by the various canals is one of the greatest importance as the data forms the basis for distribution of supplies between provinces, states and individual canals lying on the river system. For proper planning and management of water resources in the country, there is a continuous need to know the quantity and quality of the streams. Pakistan is far behind to adopt new techniques for water control. To determine flow in a river or channel, different types of techniques are being used in different countries. In Indo Pak, still conventional methods are in use. With the help of electronic devices like computers, acoustic methods have been successfully used for velocity and flow rate measurement for several years. These techniques are practically economical where high accuracy is required and head losses can be avoided. The present paper covering Part A highlights the basic function; operational approach and use of acoustic flow meters to determine volume flow rate in open channels while Part B what will be presented in the next proceedings shall cover the scope and its suitability particularly with reference to canal irrigation system in Pakistan. Later Part B shall also show the experience in the country with conventional flow meters.

INTRODUCTION

Pakistan has 3rd largest irrigation system in the world. The irrigation systems involve various type of water measurement structures. This comprises of Parshall Flumes, Weirs, Open Flow Meters, and constant Head orifices. With the help of electronic and computerized management, it has become possible to adopt a more reliable approach by using acoustic velocity meters, and magnetic flow meters. The use of particular structure depends on head available, site location, cost, operation and maintenance characteristics. To control water and its proper use is of greatest importance for our national resources. There is always growing demand to know the actual quantity of various canals in the system.

The acoustic flow meter is a very reliable instrument and is well accepted throughout the world. The first system was designed and installed in January 1968 at the Columbia River at the Dallas Oregon. Around the world, about 400 flow meters have been installed, some up to 450 meters wide. The worldwide survey done in 1981 by Laenen and Smith (2) showed that at least 245 acoustic velocity meters are in operational condition to measure stream discharge greater than 10 meters in width. The table 1 shows the worldwide network of open channel flow meters. In Pakistan, nine acoustic flow meters (table 2) are installed on Tarbela Dam for flow measurements which are working as per design conditions for the last six years.

The conventional stage discharge techniques are now superseding by computerized water measurement methods. The worldwide electronic acoustic technique provides a method of obtaining the independent discharge measurement. The United States Geological Survey (USGS) has more than 200 systems installed throughout the U.S., including more than 70 in Florida. Overall, the acoustic equipment has been very reliable for discharge measurement both in pipe and open channel flow.

HISTORY OF STANDARD METER FLUMES

In irrigation practice of Provincial Irrigation Departments, standard meter flume made of masonry permanent structure is adopted on many canals to measure the discharge based on non-modular flow conditions. The standard meter flume consists of up stream transition, throat and down stream transition. The throat has usually control section where critical depth occurs and its discharge is dependent only on the up stream gauge located at a point where water level is stable. The board crested metering structure is of standard design and commonly used in Pakistan. The discharge of the weir is a function of its dimensions and up stream level measured in the well. The table of up stream levels verses their respective discharge is calculated with the board crested weir formula and verified by the current meter.

The first detailed study was done by E.S. Crump I.S.E. Punjab Irrigation in 1920-23 on long crested weirs. Later on, K.R. Sharma improved the original design of Crump meter flume. In 1925, F.H. Burkett proposed the idea of head less meter in his paper no. 125 Punjab Engineering Congress, Lahore. Again, K.R. Sharma improved the defects of Burkett's headless meter and presented his own Sharma's headless meter, which was suitable for only small discharges. Sharma used submerged discharge coefficient for modular flow conditions.

Parshall flumes and Cut throat flumes are usually designed for inline open channel measuring structures for discharges up to 3000 cusecs in which canal water flows over a broad, flat converging section through a narrow downward sloping throat section and then diverges on an upward sloping floor. But both have disadvantage of either high crest or high magnitude of friction losses.

Weirs are classified by the shape of their openings. These openings can be either sharp crested or board crested. Weirs are overflow structures built across open channels to measure rate of flow of water. They have been used for many years and if they are built correctly and maintained properly, offer a simple and reliable method for water measurement but experience has shown that Board Crested Weir does not permit modular flow conditions while long throated flume again has the problem of either high crest or critical depth does not occur. Weirs are suitable where adequate head is available. Usually Weirs impose greater head loss in the canal system than other water measurement structures.

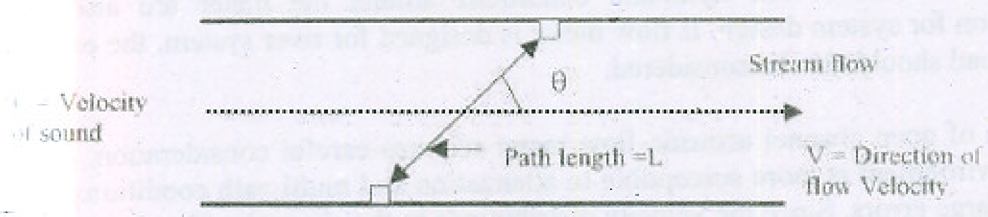
ACOUSTIC PRINCIPLE

The acoustic flow meter system can work I a wide variety of stream flow conditions and have accuracy up to 3 percent for stream discharge. The system is attached with signal cable to multiple pairs of transducers which are placed diagonally across the stream at an angle of about 30 or 40 or 45 degrees from each other at well defined elevations as shown in Fig 1. The pulses are transmitted upstream and downstream from these locations. Acoustic paths span the entire stream width. The differential travel time approach is used in which velocity is determined when a pulse travels downstream faster then a pulse traveling upstream.

The system is usually handled by computer that controls all basic timing and switching functions, all arithmetic functions and formulation of data output. Systems are usually programmed to convert the stage and velocity data into discharge. The system is usually designed to make acoustic transmissions every 4 to 10 seconds and output stage, velocity and dischat3ge about every 10 minutes accompanied by hourly and daily discharge.

THEORETICAL ACOUSTIC CONCEPT

The propagation velocity of acoustic signals is changed when the component of the liquid velocity is parallel to the direction of acoustic propagation. The average liquid velocity on each path is determined by measurement of the acoustic travel time in each direction. The liquid velocity measured at each path is integrated across the flowing area to determine the total volume flow rate. The mathematical equations used for acoustic line velocity (3) are presented as:



T_{UP} = Travel time upstream = $L / (C - V \cos\theta)$ ------------1

TDN = Travel time downstream = $L / (C. + V \cos\theta)$ ------------ 2

ΔT = Travel time difference = $T_{UP} - T_{DP}$ ------------ 3

After simplifying,

$\Delta T = 2VL \cos\theta / (C^2 - V^2 \cos 2\theta)$ ------------ 4

Since $\cos\theta \leq 1$ and $V^2 << C^2$

$\Delta T \cong 2VL \cos\theta / C^2$ ------------------ 5

But $C \cong L / T$ where $T = (T_{UP} + T_{DN}) / 2$ ----------------- 6

Flow velocity, $V \cong \Delta T .\ L / (T^2\ 2\cos\theta)$ ------------------ 7

From last equation, the flow velocity at the acoustic path can easily be calculated by knowing the path angle, path length with channel center line and measuring the time for the acoustic pulse to travel between the transducers in the upstream and downstream directions. The velocities for these paths are then integrated and the flow calculated from the velocity vectors and channel geometry.

SYSTEM COMPONENTS

An acoustic flow meter consists of an electronic processing unit and several pairs of acoustic transducers and associating cabling. The system is energized with 20 volts, DC battery, which can be charged from different power sources. The solar energy source is also available with the system being more economical. The typical flow diagram with necessary components is depicted in Fig 2. A control cabin of suitable size is also a part of the system.

ACOUSTIC REQUIREMENTS

The design of acoustic flow meter involves many parameters like range of volume flow rage, channel type, site requirement, accuracy, head available, cost, maintenance and operational constraints. The hydraulic conditions around the meter are also major consideration for system design. If flow meter is designed for river system, the estimated sediment load should also be considered.

The design of open channel acoustic flow meter requires careful consideration, as open channel environment is more susceptible to attenuation and multi path conditions, which can inject large errors. Since the velocity distributions in the channel with open surface is not well know, either because it changes stage/flow conditions or the channel is new, in either case, additional acoustic paths can reduce system errors.

The system accuracy can often be achieved more economically with an increased number of acoustic paths than by field calibration after installation. The marginal cost of additional paths I s low given that the site work, electronics, stage measuring system, cable runs/conduits and transducers have already been paid for. The total system cost should also be compared with the site location and site development work required.

OPEN CHANNEL FLOW METER ERRORS

The desired overall system accuracy should be considered during design phase in order to establish the number of paths required. Francis C. Lowell (4) has summarized several important open channel acoustic flow meters errors. These errors are depicted in Fig.3. Most of these errors range from 0.1% to 0.2%. The most serious problem on the accuracy of flow meter occurs when the acoustic signals are sufficiently weakened or distorted so that the receiver detector misses the desired detection point on the waveform by one acoustic wavelength. The Table 3 should the results from this type of error. To overcome this defect, signal recognition circuits should be considered in the system receiver.

The proper system design keep the total error contributions due to line velocity and uncertainty in stage to within 1 % of flow for average velocity in excess of 0.5 foot per second. The following sources of error are expected in the system design.

1. Path length assumes face-to-face measurements.
2. Path angle assumes +0.1 survey accuracy.
3. Cross flow assumes crossed paths if required.
4. Error due to transducer projection depends on ration of transducer dia to path length.
5. Travel time normal error is actually the Random velocity error that can be reduced by multiple measurement averaging and its percent depends on velocity.
6. Distorted signal error can be between 1 and more than 100% depending on the velocity of flow, path length, and operating frequency.
7. Level measurement error depends on depth and method used.
8. Cross section assumes mortar lined channel.
9. Integration error varies between 1-3% and depends on system requirements.

ATTENUATION OF THE ACOUSTIC SIGNAL

The absorption and scattering of suspended sediment and floating organisms usually causes the attenuation of the acoustic signal. The table 4 shows some conservative estimates of sediment concentrations that can be handled by acoustic systems based on attenuation from spherical spreading and scattering from the most critical particle size.

The research has shown that sediment size and concentrations could have measured acoustically (10). As an example, the Sacramento River at Freeport acoustic system, with a path length of approximately 200 meters, is able to operate in water with as much as 2,200 mg/l of suspended sediment.

The modern acoustic flow meter system has the potential for using signal attenuation to measure changes or trends in suspended, sediment concentration by measurement of sound speed. The initial problems with signal attenuation by sediment concentration are now under control by the selection of proper sound waves frequencies and better design of transducers.

CONCLUSIONS

The use of an acoustic flow meter system is an economical approach to obtain highly accurate measurement of flow while minimizing head losses. The irrigation systems in the world have adopted acoustic technique. The system is highly accurate, reliable and well accepted worldwide. The new computer technology has reduced the instrumentation cost. The system can give discharge accuracy within 3 percent, which is not achievable by any other system. The acoustic path length varies from minimum 1.5 meters to maximum 1200 meters. Transducer frequencies are normally 100 to 500 kHz.

The system is highly suitable for water resource management. Acoustic flow meters utilize the multiple parallel path transit time flow measurement technique, which is designed for accurate flow measurement in pipes and open channels. The initial problems with signal attenuation by sediment concentration are not under control by the selection of proper sound waves frequencies and better design of transducers.

The acoustic velocity meter has unique features, as system maintenance is usually minimal. Where acoustic velocity metering systems must have been installed and calibrated correctly they provide excellent measurements of velocity. Good parallel flow lines are ideal but are a non-parallel flow situation in known, appropriate modifications and corrections can be made. Also, the channel cross section ideally should not change but even if there is shifting of bottom of flow depth varies, a low percentage change of cross sectional area may not be significant.

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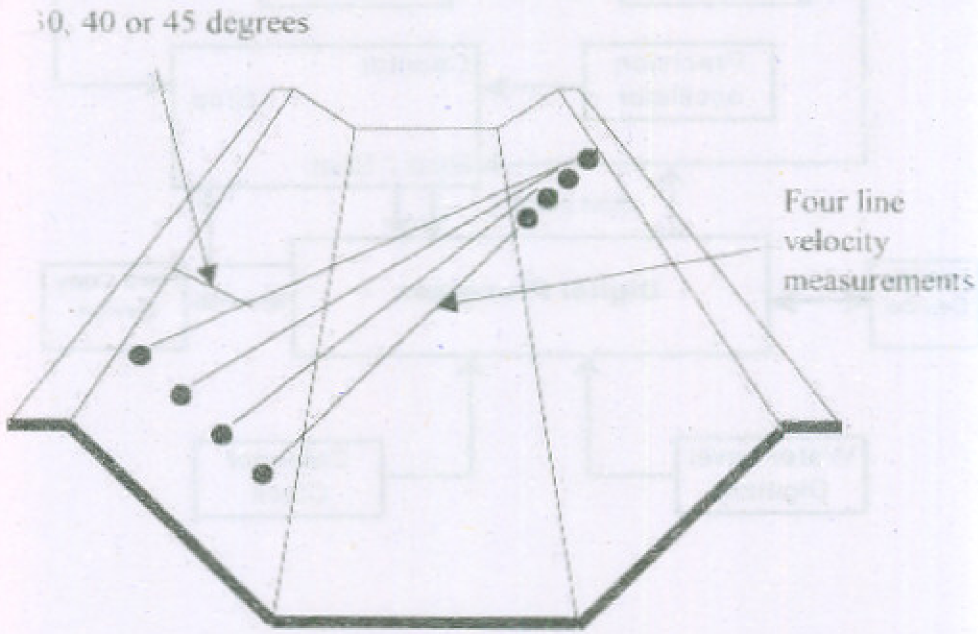

Figure 1. Channel cross section and acoustic paths placement

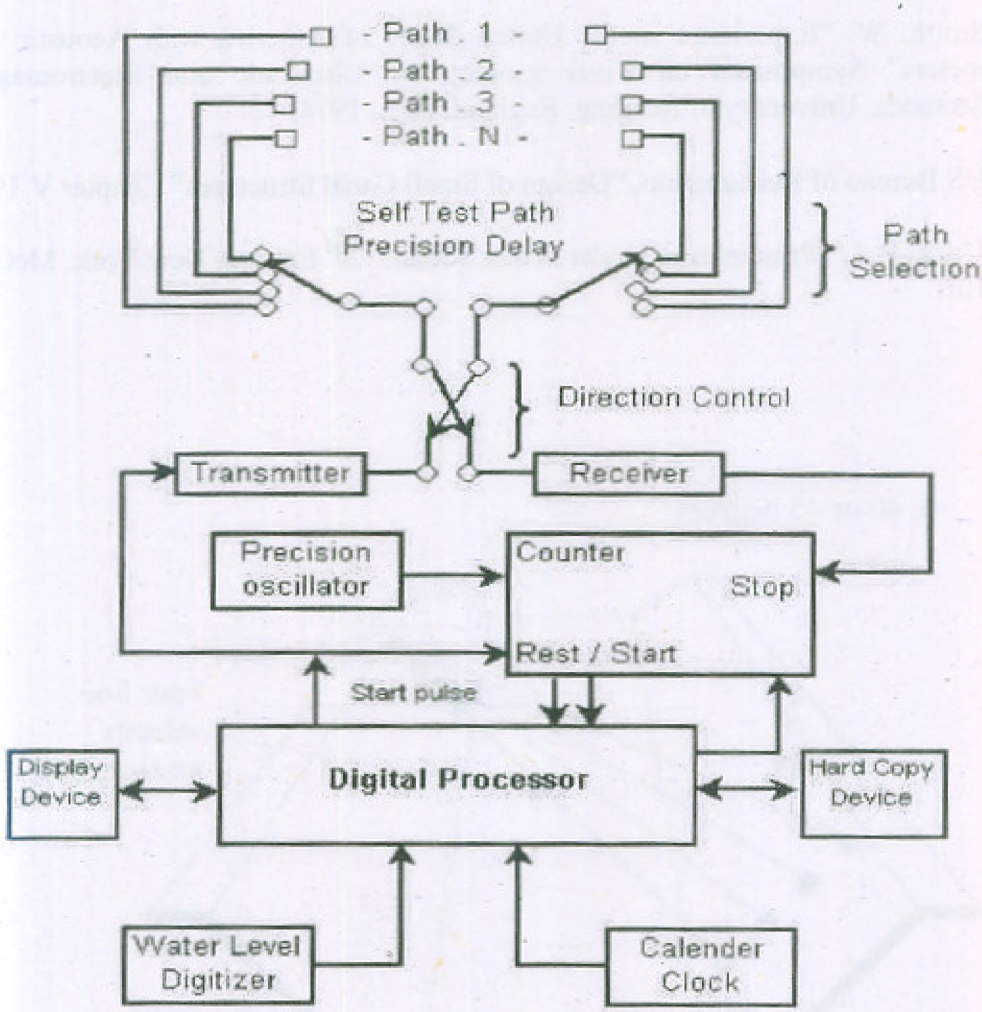

Figure 2. Typical Acoustic flow chart.

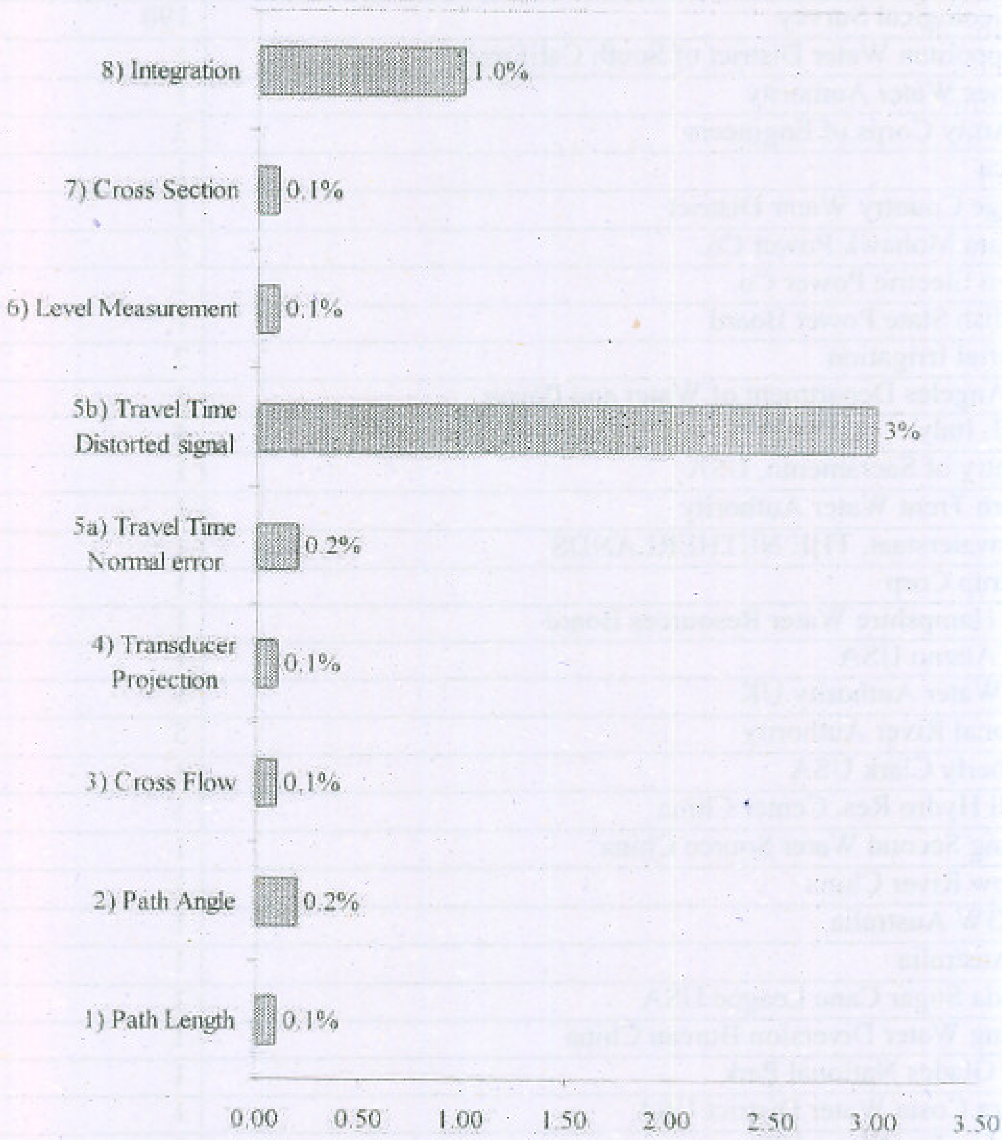

Figure 3. Open channel flow meter errors

Table 1: Worldwide network of Flow meters

Location	No. of Flow meters
California Department of Water Resources	3
US Bureau of Reclamation	6
US Geological Survey	190
Metropolitan Water District of South California	1
Themes Water Authority	1
US Army Corps of Engineers	3
Edelca	1
Orange Country Water District	1
Niagara Mohawk Power Co.	2
Tokyo Electric Power Co.	1
Swedish State Power Board	1
Imperial Irrigation	2
Los Angeles Department of Water and Power	1
ENEL Italy	4
Country of Sacramento, USA	1
Severn Trent Water Authority	1
Tijkswaterstaat, THE NETHERLANDS	1
Verdrup Corp	1
New Hampshire Water Resources Board	1
Gulf Alamo USA	1
NW Water Authority UK	1
National River Authority	5
Kimberly Clark USA	1
Small Hydro Res. Center China	1
Beijing Second Water Source China	1
Yellow River China	1
MMBW Australia	1
GS Australia	1
Florida Sugar Cane League USA	1
Beijing Water Diversion Bureau China	1
Ever Glades National Park	1
Contra Costa Water District USA	1
Lingdao Tap Water USA	1
Puget Sound Power USA	1
City of Toledo USA	1
South Florida Water Management District USA	1
University of California, Lawrence Berkley Lab	1

Table 2: Details of flow meters installed at Tarbela Dam

Location	No. Of Flow meters	No. Of Transducers
Penstock	1	16
Turbine	4	4
Relief valves	4	4

Table 3: Path length Vs operating frequency, clearance height, velocity error.

Path length (ft)	Operating Frequency (KHz)	Clearance Height (ft)	Velocity Error (fps)
500-1500	100	3.5-6.1	0.035-0.12
200-500	200	1.5-2.5	0.446-0.178
75-200	300	0.8-1.3	0.785-0.295
20-75	500	0.32-0.62	1.78-0.476
2-20	1000	0.07-0.22	8.75-0.875

Table 4: Estimates of sediment concentrations for acoustic system operation (Sediment concentration in milligrams per liter).

Selected Transducer frequency (KHz)	Path distance (meters)							
	5	20	50	100	200	300	500	1000
1000	6300	1200	400	-	-	-	-	-
500	-	3500	1200	530	230	-	-	-
300	-	7900	2800	1300	560	350	-	-
200	-	11000	4000	1800	830	520	280	-
100	-	-	10000	4600	2200	1400	770	350
30	-	-	-	-	8800	5700	3200	1500