Experimental investigations of Bias Errors of An Ultrasonic Flow meter on Sloped Pipelines

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Abstract-*Precision in flow measurement has economic consequences and also necessitates fulfilment of stipulated requirement of straight length upstream and downstream of flow meter. However, many times, the site constraints do not permit to fulfil this requirement. The use of ultrasonic meters for custody transfer applications has been grown substantially over the past several years. IEC 41(1991) recommends the use of ultrasonic flow meter as a complimentary to other flow measuring techniques for hydro turbines and other flow metering applications. The motivation of the study on installation effects is drawn from the typical water conductor system of hydro plants where the penstocks are generally sloped conduit in nature. The experimental investigation presented in this paper is to highlight and simulate the variation in accuracy for flow rate measurement for Reynolds number ranging from 0.5 x105 to 7 x105 with clamp–on ultrasonic flow meter with different sloped straight lengths The error in flow measurement by ultrasonic flow meter in straight length varied from -1.0% to +1.0% to the reference flow as per the acceptable level. Whereas, the increase of slope straight angle the percentage of shift in error is increases. The error in flow measurement in sloped pipe lines is increases with the increase in slope angles. The velocity distortion of the sloped pipes is also validated using commercial CFD Fluent solver. These findings are useful in selecting a suitable location and reference for the installation of flow meter in case of adverse site constraints.*

Keywords:-ultrasonic flow meter: flow measurement: pen stock: sloped pipelines: upstream and downstream straight lengths

I. INTRODUCTION

The importance of flow measurement in the industry has grown for the past years. Not just because it was widespread use of accounting purposes such as custody transfer of fluid for suppliers to customers. But also important due to its application in manufacturing processes and is significant for effective utilization of available resources. The custody transfer requires on entire metering system that is designed and engineered for the application and not just flow meters. It is easier to obtain a given measurement accuracy in pipes when compared to measurement in open channels. 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 selection of the proper instrument for a particular application is governed by many variables including cost. The use of ultrasonic flow meters for custody, fiscal applications has grown substantially over the past several years. The best technology in metering will not provide the expected results if it is not installed correctly or maintained properly. Hence, research study of installation effects is important in flow metering technology.

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. IEC 41(1991) recommends use of ultrasonic flow meter as complimentary to other flow measuring techniques for hydro turbines. Many times, 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. Installation effects have the potential to create swirl, asymmetric velocity profiles and secondary flows and flow separations. Each of these may be time dependent. Individually these effects may cause significant variations in the performance of flow meters. One of the practical examples (Fig.1) is that of penstock of water conductor systems of most of the hydro power plants are of sloped straight pipe line section and the uncertainty in terms of accuracy of flow meters are not addressed yet. Thus, installation effects are considered as one of the most serious origin of errors in flow measurements and needs to be addressed.

All commonly used flow meter types are too affected to different extent due to condition of installation in terms of upstream straight length [1]. It has also been shown by various researchers [2,3,4,5] through their experimental work with single and double elbows in front of ultrasonic flow meter that it lead to error in flow measurement. Further it has been demonstrated [6,7] that pulsating flow will give rise to error in flow measurement .The effect of velocity distribution at inlet of ultrasonic flow meter on flow measurement accuracy was also studied [8]. Methods of evaluating the performance of electromagnetic flow meter are given in ISO 9104 [9]. Experimental measurement of installation effects on flow meters is studied [10, 11, 12 and 13]. The accuracy of flow measurement of ultrasonic flow meters is also affected by different flow disturbances. The analysis of flow in sloped straight pipes is not addressed yet. The present paper addresses the effect of various degrees of sloped straight pipes using a single channel clamp on ultrasonic flow meter over the velocity from 0.5 to 6 m/s which has been established at flow calibration laboratory.

II. EXPERIMENTAL INVESTIGATIONS

A. Test Circuit

Experimental investigations were undertaken in high precision flow meter calibration facility to assess the extent of deviation in flow rate indicated by the ultrasonic flow meter owing to existence of various flow distorting pipe elements upstream of flow meters vis-à-vis shortage of straight length between above pipe elements and flow meters. Over the operating range, the value of flow rate displayed by the flow meter was found to be deviating as compared with true value of flow rate as measured by primary volumetric standard. This deviation was due to distorted flow profile owing to presence of flow distorting elements installed in the test circuit for experimental purpose. This facility at CWPRS, equipped with a primary volumetric standard with traceability to National Standards, is being used for volumetric calibration of flow meters as well as for assessing performance of other flow elements like valves and filters etc. (Fig.1). The discharge delivered by the main service and booster pumps is fed through the test line where test flow meter is installed. The various undesirable piping configurations upstream of flow meter were simulated in this length for experimental investigations.

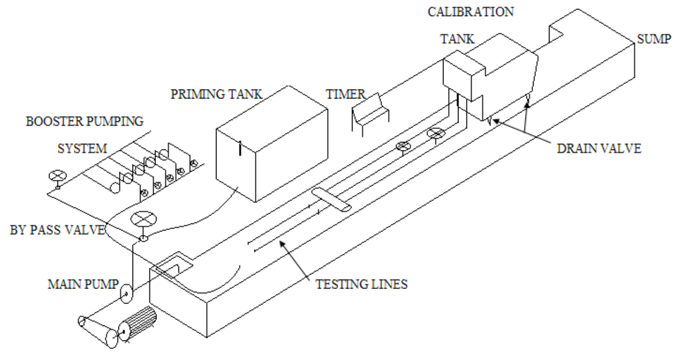

Fig.1: Calibration circuit at CWPRS, Pune

Fig. 2: Installation of ultrasonic flow sensors at straight pipe

B. Instrumentation

The details of instruments used:

Flow meter	: Controlotron 1010, Ultrasonic Clamp on type flow meter 100 mm NB
Flow Rate	: $\pm$ 0.3 % by volumetric method
Time	: 0.001 second with digital timer
Flow stability	: 0.001 % of set flow rate

C. Research Studies

The effects of presence of flow distorting elements on flow measurement uncertainty were established by clamp on type Ultrasonic Flow meter. The experiments were conducted on various piping configuration of straight pipe line, sloped pipelines of 3^o, 6^o, 12^o and 24^o degree with sufficient length at upstream and downstream of the pipes as per standards.

Fig.3 and 4 shows the experimental setup for pipe lines sloped at 6^o and 24^o degree configured sections. The sensors of the ultrasonic flow meter were installed on pipe in 'V' traverse of ultrasonic beam method i.e. with reflect mode. These experiments were conducted with 100 mm dia of piping and the percentage errors in flow measurement with respect to true flow indicatedvolumetrically are observed in flow range of 10 to170 m^3/hr.

Fig. 3: Ultrasonic flow meter installed at 6° sloped pipe

Fig. 4: Ultrasonic flow meter installed at 24° sloped pipe

III. RESULTS AND DISCUSSIONS

Exhaustive experiments were conducted with 3°, 6°,12°and 24° piping configurations using single channel ultrasonic clamp-on flow meter. The associated extent of errors in the flow measurement on diameter of 100 mm NB with varying flow rate at flow distortion configurations are indicated in Tables 1- 5. The table 1 indicates that the extent of error in flow measurement for a straight length of pipe line varies from -1.0 to +1.0 percentage of the measured value. The extent of error in flow measurement in 3° and6°degree sloped pipe lines varies from -9.0 to -12.0 percentages. Where as in the case of 12°and 24° degree sloped pipe lines, the extent of error varies up from -12 to -15.0%. Figure 5-15 shows respective errors with different flow rates in terms of Reynolds numbers and velocity distortion using CFD Fluent solver.

Table 1: Error on Straight Length Pipe Using UFM

Velocity (m/s)	Metered Flow (m3/hr)	Percentage Error	Reynolds Number
0.50	14.397	0.530	56179.77
1.06	30.455	0.737	119101.12
1.61	45.516	-0.450	181685.39
1.83	52.123	0.290	206632.63
2.47	70.439	0.609	277528.08
3.12	88.116	-0.239	351123.59
3.45	97.946	0.198	387640.44
3.89	109.966	-0.069	437078.65
4.51	126.986	-0.369	506741.57
5.31	148.948	-0.840	596629.21
5.66	159.518	-0.430	635955.05
5.95	167.955	-0.250	668539.32

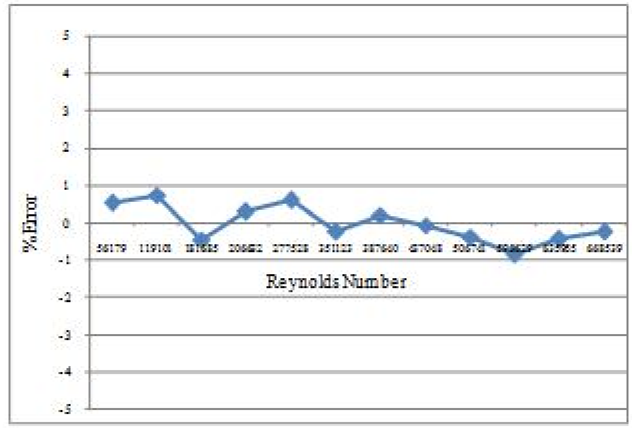

Fig. 5:% Shift in Error with Reynolds Number

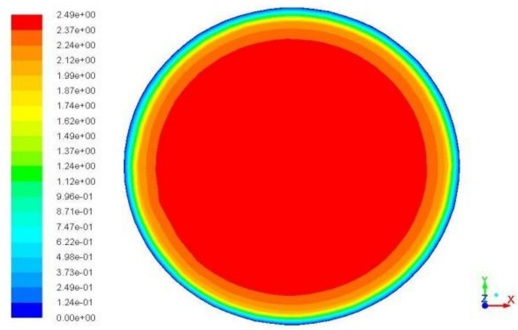

Fig. 6: Velocity Magnitude on Straight Pipe

Table 2: Error for 3° Sloped Pipe using UFM

Velocity (m/s)	Metered Flow (m3/hr)	Percentage Error	Reynolds Number
0.51	13.357	-9.873	58314
1.05	27.178	-9.734	118539
1.38	38.692	-9.643	155730
1.93	49.817	-9.853	217528
2.32	59.697	-9.903	260786
3.05	77.980	-9.932	340786
3.57	92.206	-9.452	401235
4.18	107.656	-9.885	470337
4.49	116.013	-9.572	505393
4.96	128.232	-9.432	557865
5.45	141.098	-9.322	613258
5.73	148.327	-9.218	644044

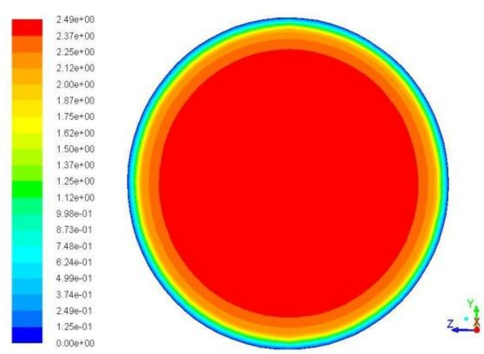

Fig. 7: Velocity Magnitude on 3° Slope Pipe

Table 3: Error for 6° Sloped Pipe Using UFM

Velocity (m/s)	Metered Flow (m^3/hr)	Percentage Error	Reynolds Number
0.51	12.914	-11.85	57415
1.07	27.182	-11.55	120449
1.53	38.915	-11.64	172696
2.02	51.041	-11.90	227078
2.50	63.221	-11.86	280898
3.03	76.523	-11.94	340449
3.56	90.042	-11.81	400000
4.03	102.010	-11.87	452808
4.54	115.079	-11.71	510112
5.07	128.590	-11.55	569662
5.57	141.408	-11.45	625842
5.88	159.360	-11.33	660674

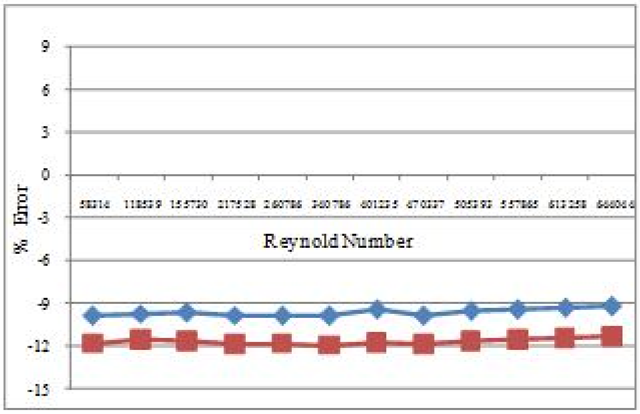

Fig. 8:% Shift in Error with Reynolds Number

Table 4: Error for 12° Sloped Pipe Using UFM

Velocity (m/s)	Metered Flow (m^3/hr)	Percentage Error	Reynolds Number
0.52	13.244	-12.45	059213
1.05	26.473	-12.83	118764
1.52	38.307	-12.65	171573
2.05	51.629	-12.59	231123
2.54	63.880	-12.72	286292
3.01	75.433	-12.84	338426
3.50	87.997	-12.49	393483
4.10	103.157	-12.51	461460
4.52	113.596	-12.67	508876
5.23	131.162	-12.77	588089
5.50	137.930	-12.81	618651
5.98	150.170	-12.61	672359

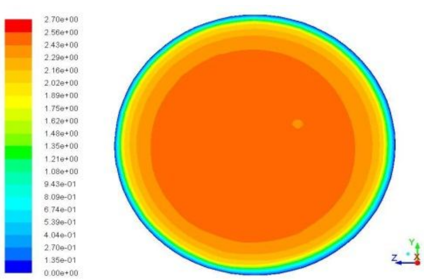

Fig.9: Velocity Magnitude on 12° Slope Pipe

Table 5: Error for 24° Slope Pipe Using UFM

Velocity (m/s)	Metered Flow (m^3/hr)	Percentage Error	Reynolds Number
0.50	12.649	-13.84	057191
1.03	25.793	-13.69	116516
1.50	37.371	-13.66	168876
2.22	55.427	-13.55	250224
2.56	63.696	-13.94	288539
3.03	75.101	-14.05	340449
3.71	91.815	-14.20	416853
3.97	98.235	-14.34	446516
4.43	109.436	-14.52	498202
4.98	122.755	-14.72	559887
5.58	137.271	-15.04	627865
6.03	148.392	-14.92	677977

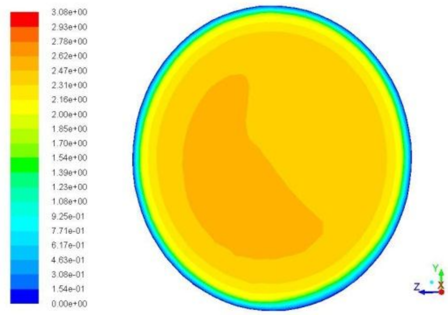

Fig. 10: Velocity Magnitude on 24° Slope Pipe

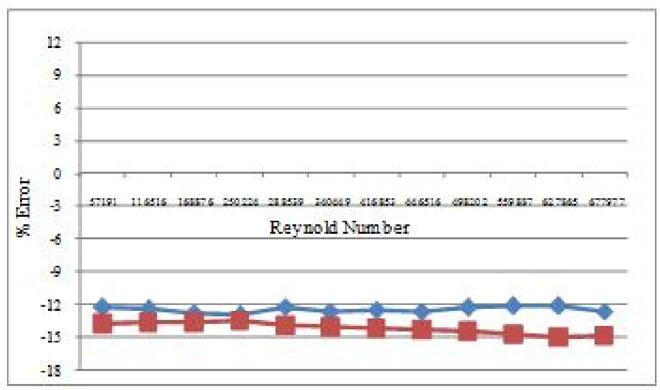

Fig. 11:% Shift in Error with Reynolds Number

IV. CONCLUSION

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 correlate the effect of significant upstream flow conditions in sloped straight lengths on the accuracy of flow measurement using Ultrasonic Flow Meter. The results shows extent of deviation of measured flow rate from its true value for sloped pipe lines is more than straight length of piping due to installation effects and flow turbulences. In general, it may be concluded that the ultrasonic flow meter is sensitive to swirl due to piping configuration and site conditions. The percentage of errors increases with the sloped pipe angles. The percentage of errors is of negative when compared to true values. Hence ultrasonic flow meter can be used better in accuracy for straight length configuration with sufficient straight length at upstream and downstream conditions.

These results may be considered as a reference to where standard straight lengths are not available. These findings are also useful in selecting suitable location for the installation of ultrasonic flow meters and need attention to upgrade in the available ultrasonic metering technology for usage in slope pipes. Presently ultrasonic flow meters do not address the biased errors due to installation effects under sloped pipe condition. Therefore the existing ultrasonic flow metering techniques need attention for up gradation in considering site effects. The future scope may explored for slope pipe lines in reverse direction.

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