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EXPERIMENTAL INVESTIGATION OF STROUHAL'S NUMBER LINEARITY FOR DUAL TRAPEZOIDAL BLUFF BODY VORTEX FLOWMETER

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ABSTRACT:

In this paper, on an experimental facility the signal characteristics of DN50 trapezoidal dual bluff body vortex flow meter are investigated with steady flow. The results are presented for the nine dual trapezoidal bluff body combinations with opening length varying from 40.5mm to 115.5mm with blockage ratio of 0.26, 0.29 and 0.31. For each blockage ratio the influence of three after shape angle (16°, 19° and 22°) are investigated. The vortex frequency is calculated by using zero crossing method. The Linearity of Strouhal's number is used as parameter for comparison. The results show that the vortex frequency increases for the 0.26 and 0.29 blockage ratio by using dual bluff body. For the 0.31 blockage ratio, the vortex frequencies is almost same or less for all after shape angles and opening lengths than the reference single bluff body. The best linearity of Strouhal's number was observed for 22° after shape angle combinations for all blockage ratios.

KEYWORDS: Bluff body; Strouhal Number; Dual bluff body.

I. INTRODUCTION :

The vortex flow meter is used for various applications because of its robust design and no moving parts in flow stream. The phenomenon of vortex shedding from bluff bodies has been studied since the pioneering work of Strouhal (1878) and Von Karman (1912). When a bluff body is placed in a flow stream, vortices shed alternately from each of the side surfaces of the body. The non-dimensional Strouhal number (*Str*), as defined in Eq.(1) is constant for the complete flow range of meter and hence can be used to calculate flowrate when vortex frequency is known.

$$Str = \frac{f \times d}{U_m} \qquad (1)$$

Where
f = Vortex shedding frequency
d = Diameter of bluff body
U_m = Mean free stream velocity

However, the vortex flowmeter has its own disadvantage i.e. poor noise immunity and low-flowrate sensitivity. In order to improve the noise sensitivity and performance at low- flowrate great efforts are made by researchers in area of improving signal to noise ratio, BB shapes and signal processing techniques. The experimental results of two bluff bodies in tandem showed that there was considerable improvement in vortex frequency. Bentley and Benson [1] investigated experimentally the performance of various rectangular shape bluff bodies combinations. They proposed the condition for optimum vortex shedding. The work was further analyzed by visualization of vortex shedding in open channel flow by Bentley and Mudd [2].They suggested that the combination of rectangular upstream and triangular downstream bluff body combination gave highest repeatability. Fu and Yang [3] investigated the hydrodynamic vibrations characteristics of dual triangular bluff bodies The simulation results for the dual triangular bluff body combinations suggests that the signal to noise can be increased and the flow turndown ratio can also be improved for vortex flow meter with dual bluff body combination. J. peng *et.al* [4] experimentally investigated the optimum spacing of triangular bluff bodies for various combinations of bluff body widths and distance between bluff bodies. He suggested that the combination of bluff bodies having the equal bluff body width (d1=d2=13mm) or d/D =0.26, and opening length of 60-65mm or L/d = 4.6-5, the vortex generation is strong and regular shedding occurs.

Most of the previous work, which is aimed at improving the low flow rate sensitivity and repeatability of vortex flow meter by using two bluff bodies in series, was related to rectangular and triangular bluff bodies. The Trapezoidal bluff body is popularly used in Vortex flowmeter because of its ease of manufacturing. After body shape i.e. the shape of bluff body after flow separation point influences the vortex signal and linearity in considerable manner. The mathematical model often gives a deterministic solution of optimization problem. As the vortex formation is influenced by various unknown parameters, the authors of this work proposed semiempeirical optimization method based on the measured signal as the basis for the ability of bluff body to generate strong and consistent vortices. In this paper the experimental results of influence of after body shape and bluff body opening length are presented. The signal generated by dual bluff bodies with invasive paddle type capacitive sensor is compared based on the signal quality. The linearity of Strouhal's number was used to parameterizing the quality of bluff body. The best dual trapezoidal bluff body configuration is proposed based on linearity of Strouhal's number.

II. EXPERIMENTAL SET-UP:

Close water circulation loop with the 64 m^3/hr capacity pump was installed with 2 water tanks of capacity 300 liters each on ground and 2 tanks with 500 liters capacity are installed at 2 meters height. Flow regulation is done manually with the butterfly valve. The volumetric flowrate logging is done through Corilois mass flow meter. Mitsubishi type flow conditioner [5] is installed at the start of 100D upstream. The DSC (differential Switch Capacitor) type capacitive sensor as shown in Fig 1 is used to pick vortex frequencies. The data acquisition for the vortex frequencies is done by National Instrument's data logging device NI9215. The output of NI9215 is feed to Labview virtual interface through USB connection. Corilois flow mater output is configured for 0-10V corresponding to 0-50 m^3/hr and connected to NI9215. Labview program is designed to generate time stamped output csv file for vortex frequency and flow rate at sampling rate of 4000 samples per second.

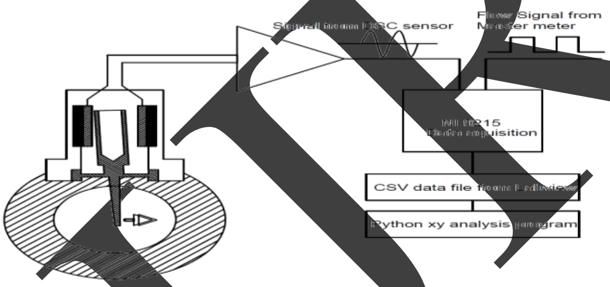

Fig 1 Vortex signal pickup arrangement

Performances of vortex flow meter at low Reynolds number get affected by poor strength of vortex signal. The electrical noise, hydrodynamic vibrations, pipe vibrations and other inferences are observed in large percentage of total energy of signal received from capacitive sensor. Venugopal et.al [6] proposed Empirical mode decomposition combined with autocorrelation decay rate to extract the vortex frequency from signal. Peng et al [4] proposed HHT algorithms to extract vortex frequency. In this experiments signal processing is done by zero crossing algorithm [7]. The signal is filtered using bandpass Butterworth filter in the range of +/- 20% of the frequency band, calculated from the reference Strouhal's number of 0.25. A clear distinguished vortex frequency can be identified with this method at very low flowrate. The power Spectrum Diagram (PSD) for the case of bluff body width 16.5 for various Reynolds number is shown in Fig.2. Considering the available computer capability to process the data, the zero crossing method is used to find the vortex frequency from the signal.

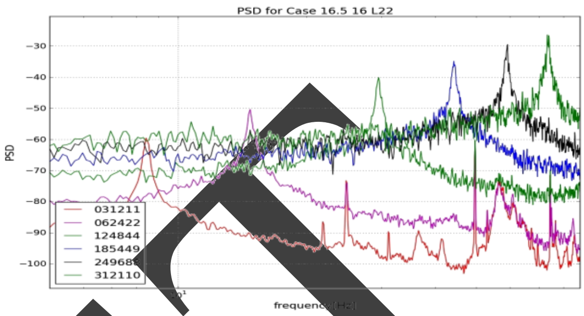

Fig 2 PSD to find Vortex frequency with Zero crossing method

III. EXPERIMENT DESIGN:

The blockage ratio in the experiments is defined as ratio of bluff body width to the inside diameter of pipe. The Experiments were performed with blockage ratios (d/D) 0.26, 0.29, and 0.31. Based on previous work [7] the sensor location is maintained at 22 mm from downstream bluff body base. The experiment combinations are as shown in Fig. 3 and the dimensions are as per Table I.

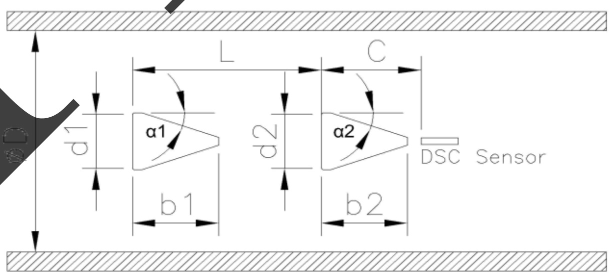

Fig 3 Experiment model of dual bluff body vortex flowmeter

TABLE I. DUAL BLUFF FLOWMETER DIMENSIONS FOR EXPERIMENT

d_1 (mm)	b_1 (mm)	α_1°			d_2 (mm)	b_2 (mm)	α_2°		
13.5	19	16	19	22	13.5	19	16	19	22
14.5	19	16	19	22	14.5	19	16	19	22
16.5	19	16	19	22	16.5	19	16	19	22

The linearity of Strouhal's number was evaluated for bluff body separation length of $3d_2$, $4d_2$, $5d_2$, $6d_2$ and $7d_2$ for each case in Table I.

The experiment combinations are defined as per One Factor per time is as per Table II. Total 9 bluff body combinations are tested with 5 separation lengths. As the purpose of the experiments is to evaluate if there is an influence of dual bluff body on vortex frequency at lower flow rates, the flow rate tested was from minimum of 0.5 *m/s* to 5 *m/s*.

TABLE II. THE BLUFF BODY COMBINATIONS FOR EXPERIMENT

Combination Number	1	2	3	4	5	6	7	8	9
d_1	13.5	13.5	13.5	14.5	14.5	14.5	16.5	16.5	16.5
α_1°	16	19	22	16	19	22	16	19	22
d_2	13.5	13.5	13.5	14.5	14.5	14.5	16.5	16.5	16.5
α_2°	16	19	22	16	19	22	16	19	22

A. LINEARITY OF STROUHAL'S NUMBER:

$\%L_{str}$ is the Linearity of Strouhal number. Linearity is calculated from equation (2). Str_i is the Strouhal number calculated for the set flow rate and $\overline{Str}$ is the mean Strouhal number for all the flow rates tested for the specific bluff body combination.

$$\%\ \varepsilon = \frac{1}{N}\sum_{i=1}^{N}\frac{|Str_i - \overline{Str}|}{\overline{Str}} \times 100 \qquad (2)$$

IV. RESULTS AND DISCUSSIONS:

The experiments are done with steel pipe of 52.5mm diameter with water. The flow velocities are gradually increased from 0.5m/s to 5 m/s. To understand the influence of after body shape of dual bluff body combination, the experiments are performed with nine combinations as per Table II.

The results of Strouhal's number and Linearity of Strouhal's number for bluff body separation length of $3d_2$, $4d_2$, $5d_2$, $6d_2$, and $7d_2$ are shown in Fig. 4 to Fig 12. The results of single bluff body with same width and after body angle from previous experiments are used as reference for comparison.

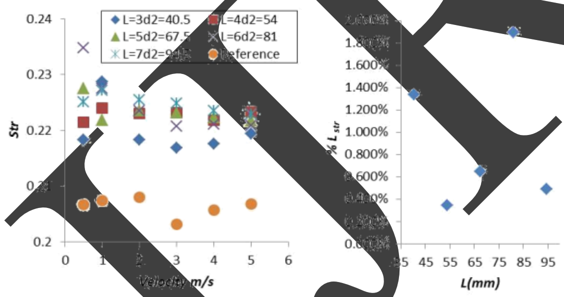

Fig 4 Strouhal's number and Linearity of Strouhal's number for combination 1

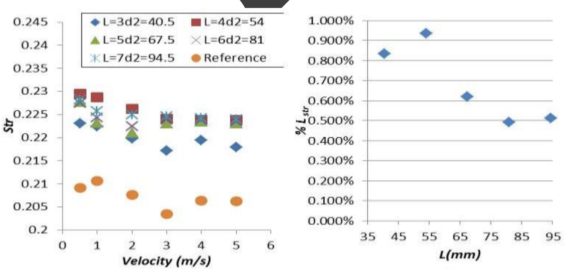

Fig 5 Strouhal's number and Linearity of Strouhal's number for combination 2

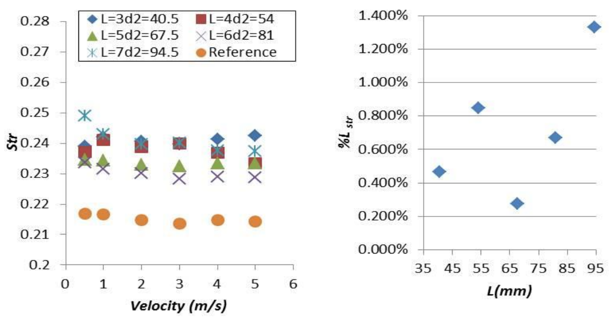

Fig 6 Strouhal's number and Linearity of Strouhal's number for combination 3

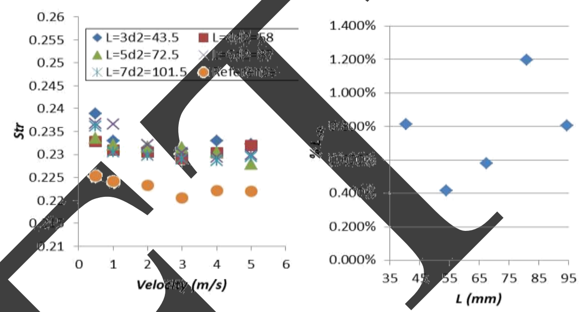

Fig 7 Strouhal's number and Linearity of Strouhal's number for combination 4

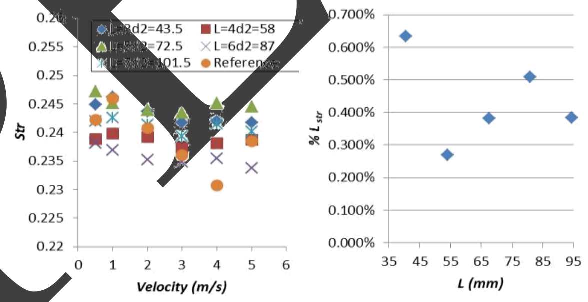

Fig 8 Strouhal's number and Linearity of Strouhal's number for combination 5

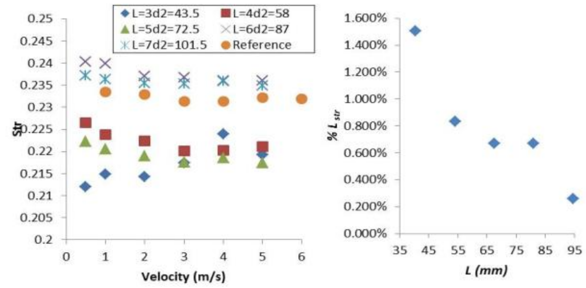

Fig 9 Strouhal's number and Linearity of Strouhal's number for combination 6

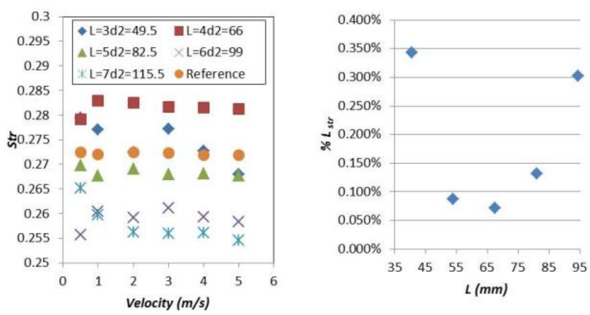

Fig 10 Strouhal's number and Linearity of Strouhal's number for combination 7

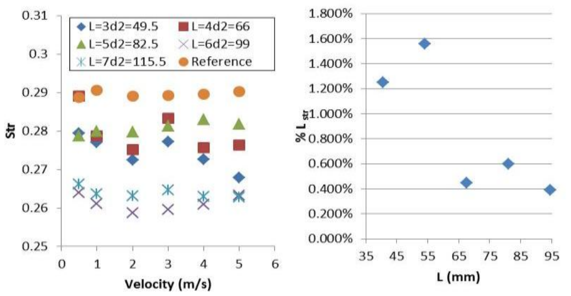

Fig 11 Strouhal's number and Linearity of Strouhal's number for combination 8

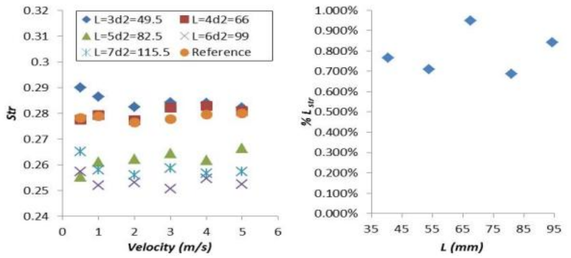

Fig 12 Strouhal's number and Linearity of Strouhal's number for combination 9

Following are the observations summarized from the results.

1. The Strouhal's number for bluff body combinations 1 to 4 is less than the reference bluff body. .It is observed that with increase in bluff body width the strouhal's number increases. The increase in Strouhal's number is also noted with the increase in after body angle for the same bluff body width.
2. The Strouhal's number is almost same as reference bluff body for combination No.5
3. For combination No.6, the Strouhal's number is higher than reference bluff body for the opening length of $6d_2$ and $7d_2$
4. The results for combinations No.7 shows that for the bluff body opening length of $3d_2$ and $4d_2$, the Strouhal's number is higher than the reference bluff body.
5. For the combination No.8, the Strouhal's number of dual bluff body is less than the reference bluff body
6. For the combination 9 the Strouhal's number is almost same as reference bluff body for opening length of $3d_2$ and $4d_2$. For opening length more than 4d1, the Strouhal's number is considerably less than the reference bluff body.

The opening length of bluff body has considerable influence on the vortex frequency. For the combinations 1 to 6, the bluff body width is less than the reference bluff body. The increase in bluff body width and after shape angle shows increase in Strouhal's number.

V. CONCLUSIONS:

The vortex frequency as mentioned earlier depends on lot of factors. The obtained results from the tests confirm that the vortex shedding frequency increases with dual trapezoidal bluff body construction. However dual bluff body shows a negative influence on the linearity of Strouhal's number. On the basis of obtained results, it could be concluded that after body shape angle and opening length of bluff body has significant influence on overall optimization of Vortex flowmeter. The results of experiments can be summarized as

1. The vortex frequency at low flowrate increases with dual bluff body construction for blockage ratio d/D = 0.26 for all opening length of dual bluff body. The best Linearity is achieved for 22° after shape angle combination with opening length of $5d_1$.
2. For the blockage ratio of 0.29, and after shape angle 16°, Vortex frequency increases for all opening lengths than the reference single bluff body. For after shape angle the vortex frequency is less than reference for all opening lengths except $6d_2$ and $7d_2$.Vortex frequency increases for opening length of $6d_2$ and $7d_1$.The best Linearity of Strouhal's number for blockage ratio was observed for 22° after shape angle at $7d_2$ opening length.
3. For the blockage ratio of 0.31, the vortex frequency is almost same or reduces for all after shape angles and bluff body opening lengths than the reference bluff body.

The experimental result shows that vortex frequency increases for 0.26 and 0.29 blockage ratios at lower flowrates and hence these are recommended blockage ratio's with after shape angle of 22°.

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