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INFLUENCE OF AFTERBODY SHAPE ANGLE OF TRAPEZOIDAL BLUFF BODY ON MEASURED SIGNAL PARAMETERS

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ABSTRACT:

In this paper the problem of vortex flowmeter optimization is considered. The experimental study of the influence of after body angle along with blockage ratio for the trapezoidal bluff body is presented. Linearity of Strouhal's number, quality of signal based on the standard deviation of signal period was applied as optimization criteria. The influence of after body angle on the optimization of meter was confirmed during the tests. Best trapezoidal bluff body geometry was proposed based on the Linearity of Strouhal's number

Keywords: Bluff body; Strouhal number; Blockage ratio; Vortex.

I. INTRODUCTION:

The vortex flow meters are universally used because of robust design and no moving part. 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 bluff body. As it is well known that the vortex signal quality and linearity depends on bluff body shape and dimension, research in this field is limited to the two dimensional bluff body shapes with different blockage ratio. Cylinder is the most widely studied bluff body geometry being many applications of cylindrical shape around us. Amongst the other blunt shape bluff bodies, the trapezoid shape bluff bodies are the strongest vortex generators and hence are studied by researchers. The studies by Igarishi [1] to improve the performance of flowmeter concluded that the circular bluff bodies with the slit, corresponding to s/d=0.1 and d/D=0.267 is the most effective shedder. T-shaped bluff bodies proposed by Miau et al. [2] with L/d=5.6 found to be best configuration having good Strouhal number constancy. Zheng *et al.* [3] experimentally proved that with increase in the width of bluff body, signal intensity reduces along with the frequency of vortices. Ordia *et.al.* [4] studied the after body dimensions of various sharp edge bluff bodies for the vortex formation length and wake width using flow visualization method. Venugopal *et al.* [5] Studied the effects of the upstream turbulences by with dual wall differential pressure measurement method and suggests that 0.3 blockage is the best among all studied blockage ratios giving highest amplitude of signal and least uncertainty of Strouhal number. Wahed *et al.* [6] investigated the influence of cross sectional shapes of bluff body on the performance of an electrostatic vortex shedding flowmeter. From the comparison of results, the T-shaped shedder proved to be best shedder tested. This suggests that the tail section connected to flat face of the shedder plays an important role in controlling vortex shedding and produces high signal to noise ratio, which is almost constant throughout the entire meter range. Hans *et al.* [7] investigated vortex shedding flowmeters coupled with a detection of the vortex frequency by an ultrasound barrier behind bluff body. Miau *et al.* [8] investigated the fluid dynamics over an axisymmetric bluff body. The circular disks and rings are used as bluff body shapes. The findings indicate that the vortex shedding frequency can be obtained with the sensor situated on the surface of the pipe wall. Miau *et al.* [9] studied a T shaped shedder body with trapezoidal cylinder with replaceable extended plates behind the cylinder. The experimental results with six vortex shedders studied concludes that optimal vortex shedder found comprises a trapezoidal cylinder and an extended plate with L/D = 1.56-2.0, for which the linear relationship between the Strouhal number and Reynolds number is verified.

Most of the work performed around trapezoidal bluff body is related to the optimization of the blockage ratio. After body shape i.e. the shape of bluff body after flow separation point influences the vortex signal and linearity in considerable manner. Very few efforts are made to study the influence of after body shapes of trapezoidal bluff body along with blockage ratio and sensor location. In the presented work the problem of influence of whole meter configuration i.e. the trapezoidal bluff body after body shape angle with different blockage ratios and sensor locations on parameters of measured signal is considered. The vortex meter optimization problem was considered in numerous articles by mathematical modelling of physical phenomenon occurring in the vortex flowmeter. Unfortunately, making a useful mathematical model on basis of equations is still impossible as the numerical solutions results are of deterministic character. The value of deterministic solution is rather questionable as the process of vortex shedding is influenced by numerous unknown and random characters.

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. The linearity of strouhal's number obtained from signal is compared for all combinations studied. The standard deviation of signal was used to parameterizing the quality of bluff body. Characteristic of meter depends on the shape of bluff body and sensor location if it is invasive type. Hence to optimize the flowmeter all parameters need to be optimized. Considering various methods of optimization, OFAT (One Factor At Time) method is used for experimentation.

II. EXPERIMENTAL SETUP:

The experiments are performed for investigation of influence of after body shape of trapezoidal bluff body on its characteristics and the quality of measured signal. The tested geometrical parameters are bluff body shape, blockage ratio and distance between bluff body and sensor. The blockage ratio in this experiment is the ratio of bluff body width to the inside diameter of pipe.

Close water circulation loop with the 64 m^3/hr is used for the experiments. Flow regulation is done manually with the butterfly valve and the volumetric flowrate logging is done through Corilois mass flow meter. Mitsubishi type flow conditioner [10] is installed at the start of 100D upstream of test meter. The Endress+Hauser's DSC(differential Switch Capacitor) type capacitive sensor as shown in Figure 1 was 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 was 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 was designed to generate time stamped output csv file for vortex frequency and flow rate at 4000 samples per second. The sampling time was decided so as to have the number of vortex shedding periods more or less constant for all the measurements. To get approximately equal periods, the sampling time for lower flow rates was increased.The signal is processed with a program developed in Python.

Steps used in signal processing

1. The raw signal data .csv file is imported in signal processing program developed in python xy
2. The mean of signal is subtracted from signal to achieve the signal symmetry
3. Frequency calculated considering reference strouhal's number as 0.25 and was used as filter frequency
4. Signal was filtered for 20% band of filter frequency value with Bandpass Butterworth filter
5. Zero crossing frequency is calculated from filtered signal by applying Zero crossing algorithm to get the mean vortex frequency
6. PSD is plotted to check the distinct identification of vortex frequency
7. The signal quality is checked by calculating the standard deviation with mean and Standard Deviation (% SD) of frequency signal.

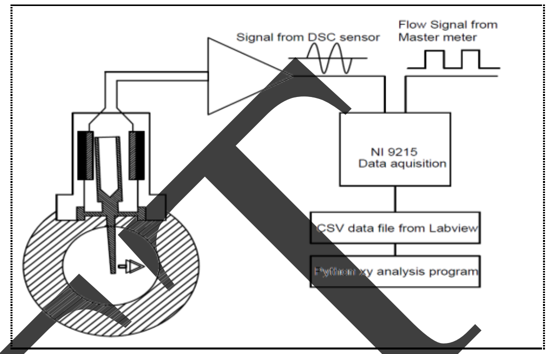

Figure 1 Vortex frequency pick up and signal processing set

III. EXPERIMENT DESIGN:

With the basis of earlier experience trapezoidal bluff body with 0.26, 0.28 and 0.31 blockage ratio are selected for the tests. The after body angle of 16°,19° and 22° are tested with each blockage ratio by varying the sensor location at 22mm, 39mm and 48mm. The experiment configuration is as shown in Figure 2 and Table I. The experiments were conducted for velocity range of 0.5 m/s to 5 m/s in the velocity steps are 0.5, 1,2,3,4 and 5 m/s for the each combination of bluff body and sensor location.

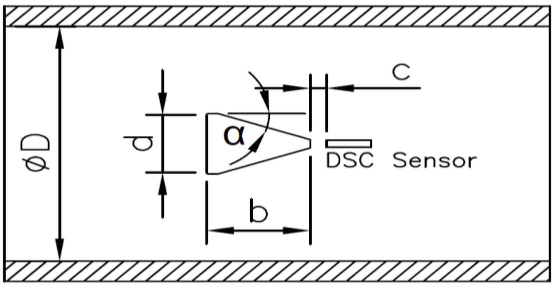

Figure 2 Dimensions of Bluff body and sensor location

TABLE I. DIMENSIONS OF BLUFF BODY AND SENSOR LOCATION

Meter ID(mm)	d(mm)	b(mm)	α°			L(mm)			Blockage ratio (d/D)
52.5	13.5	19	16	19	22	22	39	48	0.26
52.5	14.5	19	16	19	22	22	39	48	0.28
52.5	16.5	19	16	19	22	22	39	48	0.31

A. STROUHAL'S NUMBER:

The frequency of vortex generation is directly proportional to flow velocity. The non-dimensional Strouhal's number (S_{tr}) is almost constant for the complete range of flow velocity of meter. The Strouhal's number is calculated from equation

$$Str = f \times d / Um \qquad (1)$$

Where

f – Vortex frequency
d – bluff body width
U_m – Mean flow velocity

B. *Linearity of strouhal's number:*

The Linearity of Strouhal's number is calculated from equation

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

Where

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.

C. *Uncertainty:*

The Strouhal's number is calculated from equation

$$Str = f \times d / Um$$

The uncertainty of the frequency is calculated from following equation

$$U_f(\%) = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma_{signal} \times 1.96}{\sqrt{N_{samples}}} \qquad (3)$$

Where N is number of experiments, σ_{signal} is the standard deviation of signal with 95% confidence interval and $N_{samples}$ are the numbers of samples of signal from the zero crossing algorithms. The Average uncertainty of frequency for the experiment is 0.3 %.

The uncertainty associated with Strouhal's number is

$$U_{str}{}^2 = U_1{}^2 + U_2{}^2 + U_3{}^2 \qquad (4)$$

U_{str} – Total uncertainty in Strouhal's number
U_1 – Uncertainty of vortex frequency
U_2 – Uncertainty related to Vortex bluff body width
U_3 – Uncertainty of flow test rig calculated from Reynolds number

$$U_{Str}(\%) = \sqrt{(0.3)^2 + \left(\frac{0.1}{13.5}\right)^2 + (0.03)^2}$$

$$= 0.3\ \%$$

Hence overall uncertainty associated with the Strouhal's number is 0.3 %.

IV. RESULTS AND DISCUSSIONS:

In Figure 3,Figure 4 and Figure 5, Strouhal's number vs the Reynolds number for the sensor location of 22mm,38mm and 49mm is shown for all types of bluff bodies tested. As it is seen the Strouhal's number increases with the blockage ratio and the after body shape of each blockage ratio has influence on Strouhal's number.

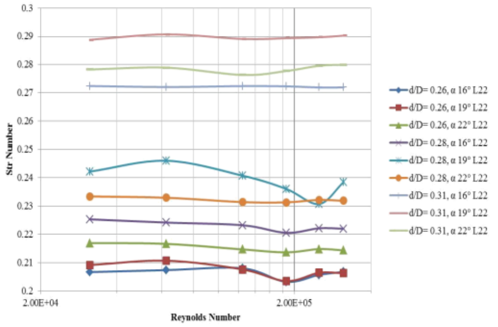

Figure 3 Strouhal's number vs Reynolds number for Sensor location 22 mm

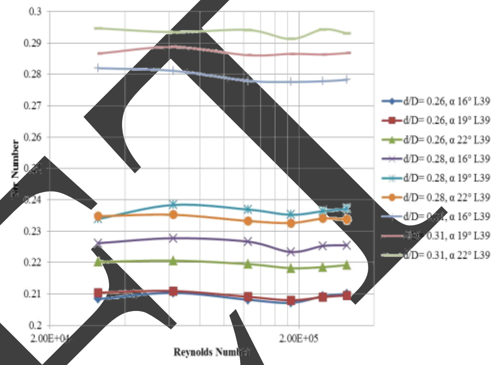

Figure 4 Strouhal's number vs Reynolds number for Sensor location 39 mm

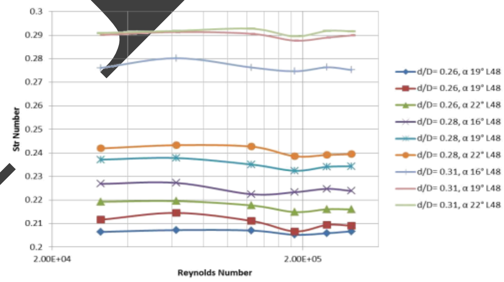

Figure 5 Strouhal's number vs Reynolds number for Sensor location 48 mm

The Strouhal's number increases with the after body shape angle. The increase in Strouhal's number is higher for the 19° angle for all blockage ratios. It is more than 22° in some cases. As Strouhal's number is directly proportional to vortex frequency, we can say that vortex frequency is strong and higher with 19° after body shape angle. The vortex frequency increases as the shear layer velocity increases because of the local increase in flow speed around bluff body with increase in blockage ratio. The increase in vortex frequency is also affected by after body shape. In visualization experiments it is observed that, the increase in after body angle reduces the wake width. The wake width is inversely proportional to the vortex frequency.

TABLE II. THE % LINEARITY OF STR NUMBER AT DIFFERENT SENSOR LOCATION

Combination No.	BB Geometry	Sensor Location in mm		
		L=22	L=39	L=48
1	d/D= 0.26, α= 16°	0.593	0.478	0.275
2	d/D= 0.26, α= 19°	0.909	0.383	0.952
3	d/D= 0.26, α =22°	0.497	0.326	0.730
4	d/D= 0.28, α= 16°	0.594	0.474	0.687
5	d/D= 0.28, α =19°	1.653	0.497	0.663
6	d/D= 0.28, α =22°	0.283	0.313	0.740
7	d/D= 0.31, α =16°	0.074	0.580	0.451
8	d/D= 0.31, α= 19°	0.196	0.216	0.330
9	d/D= 0.31, α= 22°	0.368	0.305	0.275

To get the optimized bluff body geometry and after body angle of trapezoidal shape, the Strouhal's numbers of all bluff body and sensor location test were compared for the linearity. The Strouhal's number and its linearity are calculated from the frequency for each combination of bluff body. The Strouhal's number linearity for all tested combinations is presented in Figure 7

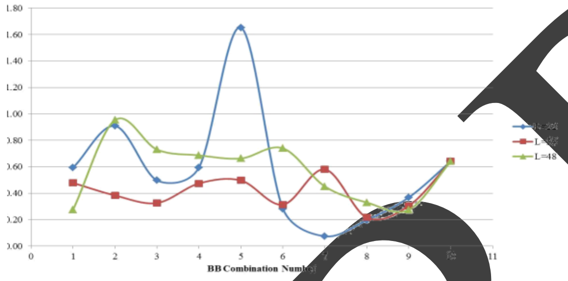

Figure 6 Linearity of Strouhal number (%) for all tested Bluff bodies

The quality of measured signal was also tested. As it results from the curves presented in Figure 3,Figure 4 and Figure 5, the quality of signal improves with d/D and after body angle.The standard deviation of signal period was used for charactrizing the quality of signal.An example of result obtained for the bluff body with d/D=0.26 is presented in Figure 7. As it can be seen, the stability of signal period strongly depends on the after body angle and the lower instability has been obtained for larger after body angle.

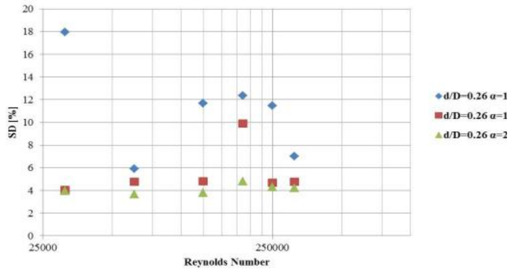

Figure 7 Relative Standard deviation of signal period vs Reynolds number

V. CONCLUSIONS:

The vortex signal as mentioned earlier depends on lot of factors. The obtained results from the tests confirms that the vortex shedding is not only affected by blockage ratio and sensor location but also by the after body shape angle in case of trapezoidal bluff body. The optimization problem is far more complicated as optimal configuration from the point of view of one parameter may not be optimum from the point of view of other parameter. For instance the Standard deviation of signal period is best for the 22° after body angle, whereas the linearity of Strouhal's number is consistent for 19° after body angle.

On the basis of obtained results, it could be concluded that after body shape angle has significant influence on overall optimization of Vortex flowmeter. The results of experiments can be summarized as

(1) The Strouhal's number linearity of bluff body with blockage ratio 0.31 with 16° angle is best (0.07 %) among all combinations tested at sensor location 22mm.

(2) The 19° angle with 0.31 blockage ratio is best combination of trapezoidal bluff body as the vortex frequency is higher with very consistent linearity of Strouhal number within 0.19% to 0.32% for all sensor location tests.

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