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Study of Vortex Shedding Behind Trapezoidal Bluff Body by Flow Visualization Method

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Abstract: **In the present study specially designed Experimental set up is fabricated to study flow visualization experiments with bluff body placed inside 50mm diameter circular pipe. Trapezoidal shape bluff body is used with blockage ratio of 0.27. Dye injection technique is used to visualize the complex vortex formation mechanism behind bluff body. The dye used is concentrated KMNO4. The study improves the understanding of complex vortex formation mechanism in the design of vortex flow meter. Various wake parameters like Strouhal number, vortex formation length and wake width are calculated. The objective of the paper is to devise an experimental setup to visualize the flow patterns obtained when a fluid flows over a trapezoidal shape vortex shedder.**

Keywords: Flow visualization, Bluff body, Strouhal number, vortex formation length, wake width, vortex shedder.

I. INTRODUCTION

Flow Visualization is a powerful tool in development and understanding of fluid dynamics. The unique advantage of this technique is that certain properties of the flow field become directly accessible to visual perception and the insight into a physical process becomes clearer. Most fluids are transparent media and their motion remains invisible to the human eye during direct observations. However, the motion of such fluids can be recognized by making use of techniques by which the flow is made visible and such techniques are called flow visualization techniques. It is also possible to derive quantitative data from the flow pictures obtained by such techniques. Information about the complete flow field can be arrived without physically interfering with fluid flows.

The vortex flow meter is based on the well-known von Karman vortex street phenomenon. This phenomenon consists on a double row of line vortices in a fluid. Under certain conditions a Karman vortex street is shed in the wake of bluff cylindrical bodies when the relative fluid velocity is perpendicular to the generators of the cylinder (Fig 1). This periodic shedding of eddies occurs first from one side of the body and then from the other, an unusual phenomenon because the oncoming flow may be perfectly steady. Vortex streets can often be seen, for example, in rivers downstream of the columns supporting a bridge. They can be created by steady winds blowing past smokestacks, transmission lines, bridges, missiles about to be launched vertically, and pipelines above ground in the desert.

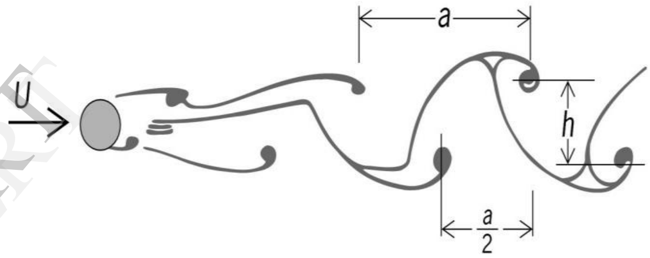

Fig. 1. Karman Vortex street phenomenon

It is obvious, that each successful meter design is determined by comprehensive understanding of applied physical phenomena. Von Karman vortex street phenomenon is very complex and sensitive on numerous physical factors. Hence, the necessity of investigations with application of miscellaneous methods. The vortex flow meter remains very attractive for industrial applications due to its high accuracy, insensitivity to the physical properties of the medium and linear dependence on frequency versus flow rate. The frequency of generated vortices is directly proportional to the flow velocity:

$$f = ST\left(\frac{v}{d}\right) \ldots\ldots.. (1)$$

Where, *S*T is the Strouhal number, *v* the fluid velocity and *d* is the bluff body diameter.

The Strouhal number *S*T is constant over a very wide range of flow velocities. In spite of the very simple equation, which describes the behavior of the vortex flow meter, the phenomena appearing in the meter are very complicated, and many unidentified factors may influence the vortex shedding. Hence, a complete description of these phenomena is not feasible, necessitating further research. Various research methods must be applied to obtain a more complete understanding of the phenomena, with each method elucidating partial information.

II. LITERATURE SURVEY

Vortex shedding was first observed by Bernard (1908) who observed alternate precision of eddies behind a circular cylinder in water, based on visible dimples on water surface. [1]. Leonardo da Vinci sat by the river side and observed the vortices shedding on the sharp edges turning up in the river. Later work carried out by von Karman was supported by flow visualization experiments. For instance, Hiementz's observations led von Karman to the theoretical description of the vortex street [2]. In the 1970s and 1980s of the 20th century, Igarashi's investigations used flow visualization as their fundamental method [3, 4]. His discovered that the existence of the slit in a circular cylinder as the bluff body considerably improves the vortex shedding was based mainly on flow visualization. His numerous experiments have confirmed an increase of the phenomenon intensity for the bluff body with a slit. The detailed analysis of the flow along the rear surface of the bluff body was made feasible by flow visualization [5]. Bentley and Mud [6] have carried out intensive investigations on dual and triple arrangement of the bluff body. Flow visualization made the analysis of the flow in consecutive stages of vortex development possible, and the influence of the secondary part of the bluff body on the quality of the phenomenon has been analyzed. The investigations carried out by Popiel *et al.* [7, 8] were also aided by flow visualization to a considerable degree. Their flow visualization experiments have led to the design of the bluff body with a concave rear surface. Splendid flow visualization pictures have confirmed the perfect matching of this rear part of the bluff body to fluid movement that the Karman street phenomenon was discovered. Gandhi *et al.* [9] used computational fluid dynamics for various shaped bluff bodies to find out best vortex shedder and concluded that a Flow meter requires a body with sharp edges to generate strong and stable vortices. Mau *et al.* [10] employed dye visualization technique to understand the vortex shedding mechanism with a ring shaped bluff bodies. Flow visualization images revealed that the presence of pipe wall affects the vortex shedding mechanism and for blockage ratio above certain values, vortex shedding was completely inhibited. Turner *et al.* [11] suggested improved vortex generator as a cylinder with a slit and concave rear face with dye visualization experiments. Pankanin *et al.* [12] based on flow visualization and image processing techniques highlighted very important aspect of convection velocity and stagnation region in the formation of cylinder wake.

In the present study, flow visualization experiments are performed for Reynolds number up to 2500.The bluff body employed is trapezoidal in shape with a blockage ratio of 0.27, which is reported as the optimum shape [13].

The broad objective of the present is to study the vortex dynamics of the trapezoidal shape bluff body placed inside a pipe and calculate straouhal number, vortex formation length, wake width.

III. EXPERIMENTAL SET UP

All the experiments were conducted in a specially designed set up for laminar flow (Re < 2500) with water as the working medium. In the set up two cylindrical tanks are provided having capacity 500 lit each. The tanks are kept at height of 2475 mm from ground level. The water from the tank is supplied to acrylic vortex flow meter through the circular pipe with inner diameter 50 mm, the flow rate from tank is controlled by using butterfly valve and globe valve .The flow conditioner is used before vortex flow meter to smoothen the flow. In series with vortex flow meter ,electromagnetic flow meter and coriolis flow meter are used .The water from the flow meter is collected into the sump and re-circulated to overhead tank by using 0.5 HP pump. The setup is as shown in Fig. 2.

For flow visualization, gravity feed method was employed to inject the dye into the flow. Carefully controlled amount of dye was injected through needles of 0.8*mm* outer diameter, without disturbing the flow. The dye used was concentrated KMNO4 (Potassium Permanganate) solution. The dye was injected into the flow from two openings of 0.8*mm* diameter, at the center of the length of the vortex shedder. The two dye injection points were located on the frontal face or near to the separation points/sharp edges respectively. The amount of dye was adjusted for each flow rate using valves to minimize the diffusion and to get better view of the shed vortices.

The region important for observing the vortex shedding phenomenon is the wake region up to 5D downstream of the vortex shedder. Videos of duration 180 s were captured for each flow rate individually using Sony HD Handy cam, with resolution of 1280*720 at the rate of 50 frames per second. The region of interest was illuminated with a white light of a compact fluorescent lamp to increase the contrast and visibility of the vortices.

Fig. 2. Test facility for flow visualization Experiments

1. Tank;2.Butterfly valve 3. Globe valve 4. Flow conditioner 5. Vortex flow meter ; 6. Electromagnetic Flow meter; 7.coriolis flow meter; 8. Sump; 9.Pump; 10.small tank for die.

Fig.3. Vortex flow meters with trapezoidal shape bluff body

Flow conditioner:

In order to achieve stable and laminar flow, Mitsubishi flow conditioner is used.

Fig. 4. Mitsubishi Flow conditioner

Bluff Body:

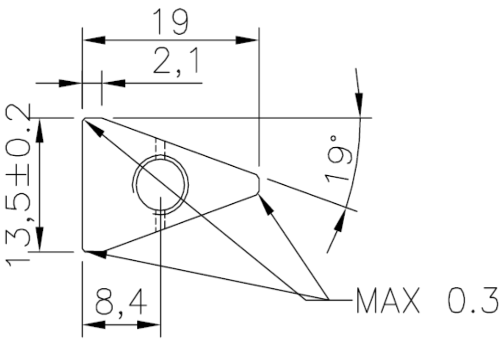

Fig. 5. Trapezoidal Bluff Body with Dimensions(mm)

Bluff Body or Vortex shedder is the heart of the vortex flow meter. The strength, linearity and stability of the vortex are defined by the shape, blockage and other geometrical parameters of the vortex shedder. The rangebility of a flow meter is primarily defined by vortex shedder. A good vortex Shedder is characterized by good strength and stability of the vortex generated least dependence of Strouhal number on the Reynolds number and minimum power losses. All these parameters depend on the geometry of the vortex shedder.

Fig. 6. Trapezoidal shape Bluff Body

The Experimental tests are conducted in Endress+Hauser Flowtec Pvt. Ltd., M-171 to 176, MIDC, Waluj Aurangabad- 431136, INDIA

IV. DATA REDUCTION

The images were taken from the flow visualization videos, which were processed using MATLAB software. The frequency is obtained from the video by finding out the number of vortices passing through an appropriate point in the image in a unit second. The bluff body width (d) is taken as the characteristic length and the average flow velocity (Um) as the characteristic velocity.

Non dimensional strouhal number St can be calculated using the relation (1) The stream wise distance between the front separation point and the point where the vortex is about to shed from the shear boundary layer, is taken as the vortex formation length (L').

The vortex formation length and the wake width were calculated by averaging the respective quantities obtained from all the separate images extracted from the videos analysis.

NOMENCLATURE

Symbol	Quantity
A	Cross sectional area of pipe (m2)
B	Blockage ratio (d/D)
D	Inner diameter of circular pipe (m)
d	Projected width of bluff body (m)
F	Frequency of vortex shedding (Hz / s-1)
l	Stream wise length of vortex shedder (m)
L	Body length of vortex shedder (m)
L	Vortex formation length (m)
Um	Mean velocity (m/s)
W	Wake width (m)
X	Stream wise coordinate (m)
Re	Reynolds number(ρ UmD/μ)
St	Strouhal number(fd/Um)
ρ	Density of fluid(kg / m3)
μ	Dynamic viscosity of fluid (Pa.s)

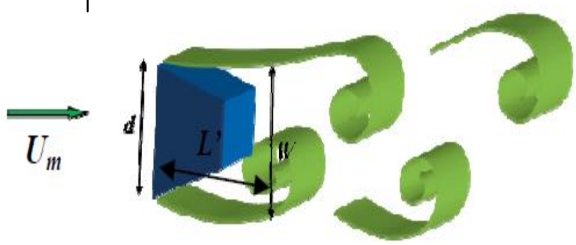

Fig. 8. Flow parameters (Lavish Ordia [14])

A. Strouhal number versus Reynolds:
The Experimental result shows that vortex shedding strats above Re>250 below Re < 250 no vortices shed.It is observed as Reynolds number increases strouhal number will increase up to Re =2500.St number remains constant for long range of Reynolds number(Re>2500)

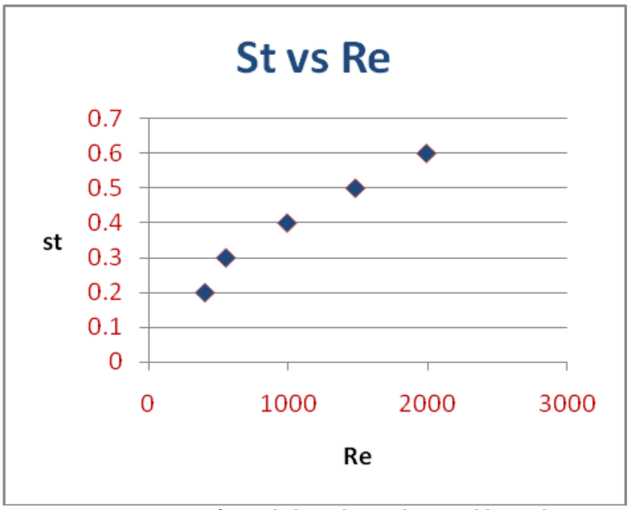

Fig. 9. Variation of Strouhal number with Reynolds number

B.Wake width versus Reynolds:
Wake width is defined as the maximum vertical distance between the two shear layers. Wake width remains constant irrespective of Reynolds number as shown in Fig.8.

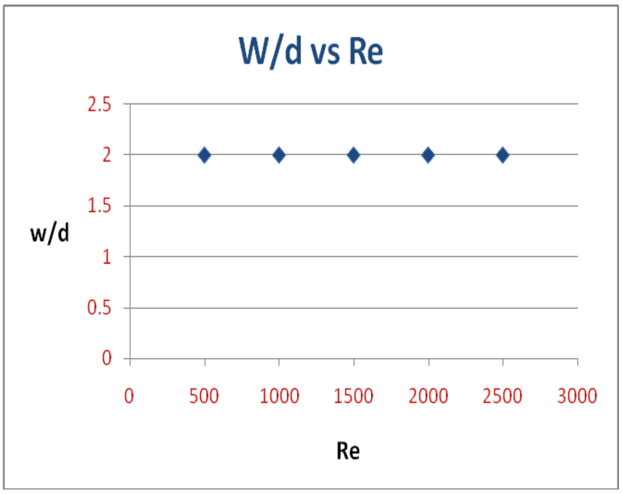

Fig.10. Variation of wake width with Reynolds number

The graphh shows that wake width remains constant in Laminar flow range.

C. Vortex formation length versus Reynolds Number:
The stream wise distance between the front separation point and the point where the vortex is about to shed from the shear boundary layer, is called as vortex formation length(L')as shown in Fig.8.

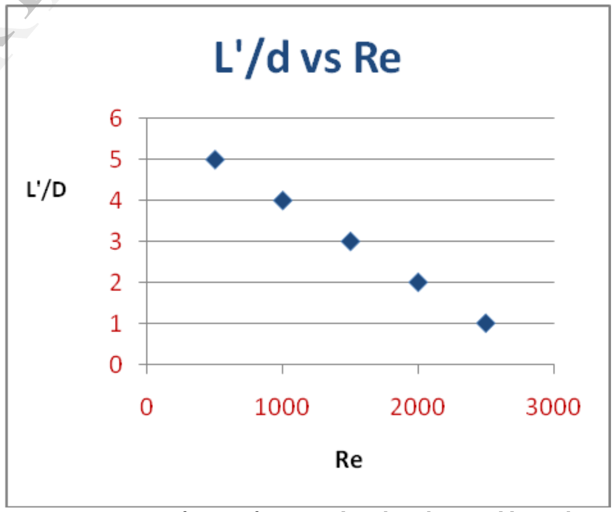

Fig.11. variation of vortex formation length with Reynolds number

Graph shows that vortex formation length reduces as Reynolds number increases

V. CONCLUSION

The wake parameters like Strouhal number, wake width and vortex formation length were studied and calculated for trapezoidal shape bluff body having blockage ratio of 0.27.
The conclusions drawn from present study are:

1.The strouhal number , vortex formation length and wake width are dependent on each other. The wake width is found to have an opposite nature to that of the vortex formation length. The wake width determines the degree of shear layer interaction, and hence the Strouhal number.

2.Results revealed that Sensor should be located at the vortex formation length so as to obtain high amplitude signal.

Results obtained are in close match with Previous Research.

ACKNOWLEDGMENT

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APPENDIX:

Vortex Shedding Images

Re=500

Re=1000

Re=1500

BIOGRAPHIES:

Apurva A kulkarni (F25) is currently pursuing masters in production Engineering at Government College of Engineering Aurangabad.She completed her B.E (Mechanical) from Modern college of Engineering, Pune.She has been awarded with the Endress+hauser scholarship for two years of Post Graduation course.

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Atul Bachal is currently working as Head Of Operations At Endress+Hauser Flowtec Pvt. Ltd,Aurangabad.He completed his B.E From KIT college of Engineering Kolhapur,He worked for Forbes marsheall Pvt.Ltd..He completed his Master of Engineering From Government college of Engineering Aurangabad.At Present he is pursuing Phd studies at Government College of Engineering Aurangabad