Vortex Shedding Meter Utilizing Flat Plate and Triangular Cylinder in Tandem

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Abstract:

In this work, the prime objective is the evaluation of the performance of vortex shedding meter utilizing the principle of closed tandem bodies, which is believed to be the first in this field. This is accomplished by performing various tests and experimental arrangements of various configurations of flat plate with triangular cylinder, under a wide range of Reynolds number. Consequently, it is found that those meters performed better than those meters that utilize single bodies for most of the arrangements tested. From the results, it is concluded that closed tandem increases the flow range, especially under low range of Reynolds numbers together with improved linearity and decreased pressure losses across the meters for all flow rates.

Key Word: Vortex, Shedding Meter, Tandem.

المستلخص:

الهدف الرئيسي في هذا البحث ، هو تقييم أداء مقياس ذرف الدوامة باستخدام مبدأ الاجسام المترادفة المغلقة، والتي يُعتقد أنها الأولى في هذا المجال. تم تحقيق ذلك من خلال إجراء العديد من الاختبارات والترتيبات التجريبية للتكوينات المختلفة للوحة مسطحة مع أسطوانة مثلثة ، تحت نطاق واسع من أرقام رينولدز. وبالتالي، فقد وجد أن أداء تلك العدادات

أفضل من تلك العدادات التي تستخدم أجسامًا مفردة لمعظم الترتيبات المختبرية. ومن النتائج، بالامكان الاستنتاج أن الترادف المغلق يزيد من نطاق التدفق، خاصة في ظل النطاق المنخفض لأرقام رينولدز جنبًا إلى جنب مع تحسين الخطية وانخفاض خسائر الضغط عبر العدادات لجميع معدلات التدفق.

Introduction:

The fluid flow around bluff circular, square, rectangular, and triangular cross-sectional cylinders has been investigated by researchers for centuries because of its importance in various engineering applications, such as electronic cooling, heat exchanger systems, bridge piers, high-rise buildings and flow dividers, sensors and probes etc. [1,2,3,10.11]. Recent developments in flow meters' design have focused on hydrodynamic instability, while measuring the flow rate of different fluids. A flow meter that uses the frequency of any suitable hydrodynamic instability to infer flow velocity and hence the volumetric flow rate is a vortex shedding flow meter.

Vortex shedding is a common fluid dynamic phenomenon, which occurs when a bluff non-streamlined body, is placed in a flowing fluid. Vortices are formed behind the obstructing body; the frequency of shedding (f) is directly proportional to fluid velocity (v) over a wide

range of Reynolds number (Re>2000) and inversely proportional to the size of the obstructing body [4].

i.e. $S = f \cdot d/u$ **…………… (1)**

S Strouhal number

f shedding frequency (cycle/sec)

d diameter or height of triangular cylinder (mm)

u air velocity (m/sec)

Vortex shedding is a two-dimensional flow phenomenon, and is highly susceptible to small three-dimensional disturbances, such as turbulence, and end-effect bluff body misalignment [5]. This phenomenon was first observed and recorded by Leonardo da Vinci as long ago as 1513[6]. However, the first experimental investigation of the phenomenon was made in 1878 by Strouhal [7]. Von Karman, in 1911, presented a theoretical representation of the vortex stress pattern.

The possibilities of flow measurement utilizing the vortex shedding were pointed out by Roshko in 1953[7]. During the 1960's a large development effort was expended on vortex meters using their potential for linear', digital output with no moving parts

The main aim of the present research is to study the effect of tandem bodies on the strength, regularity and

shedding frequency, in addition to the linearity, repeatability, flow range and pressure drop on a vortex shading meter, that employs a set of flat plate and triangle in tandem as a bluff body in different arrangements normal to the flow stream.

TEST RIG

Experimental tests were carried out in an open type wind tunnel made from lengths of PVC pipe of 75.94 mm internal diameter. The pipes were connected together by means of suitable flanges, rubber gaskets and bolts. Every precaution was taken to ensure its air tightness.

A centrifugal fan of 0.15m^3/s capacity (Manufacturer type TEFC class E) was used to suck air through the wind tunnel. The air flow rate required and hence the velocity, are regulated by means of a 50 mm ball-valve installed at the fan outlet. The air flow rate was measured using a calibrated square-edged orifice plate designed and manufactured according to B.S.,1042 part 1. The test sections or meter body were made from PERSPEX pipes of suitable dimensions, as presented in Fig. (1). The velocity fluctuation due to vortex shedding was detected by means of hot wire anemometer operating in a constant temperature mode[8,9,11], located within the

bluff body. Frequency was measured using a digital frequency meter by counting the periodic signal over 10, 100 and 1000 cycles per second depending on the velocity of the flow, shown in Fig. (2).

Figure. (1): Experimental Test

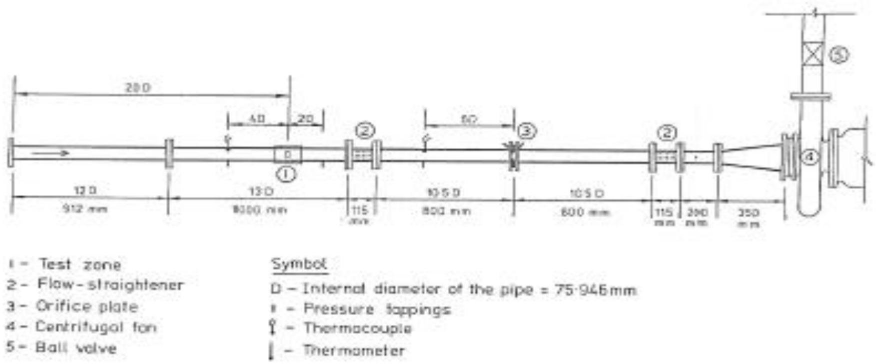
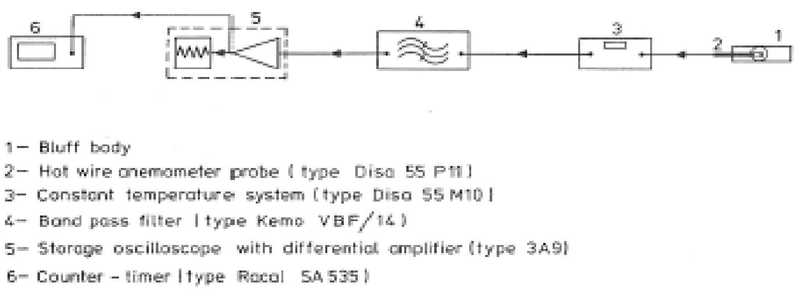


Figure. (2): Single Processing System

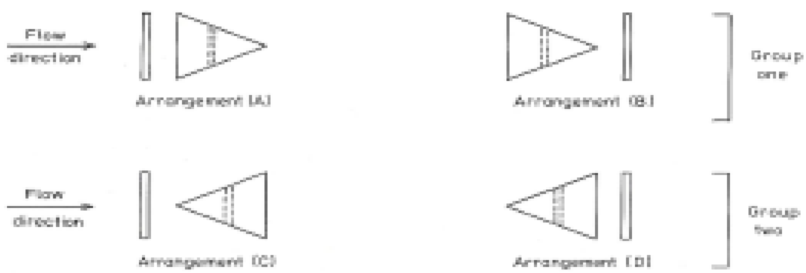


Experimental Arrangements, Results and Discussion

The effect of the flat plate in front and behind the base of the triangular cylinder, i.e. arrangements A, and B respectively, was studied. An additional study was performed for the plate in front and behind the apex of the triangular cylinder, i.e. arrangements C and D, as depicted in Fig. (3).

The following sections present the experimental results of the fore-mentioned arrangements with $1.2 \times 10^4 \le R_D \le 6 \times 10^4$, and a gap ranging from 0.0 mm to 4.064 mm. (R_D Reynold number)

Figure. (3): Flat plate and Triangular cylinder Arrangements



1. Arrangement A

In this arrangement, the plate is placed in front of the base of the triangular cylinder and normal to the flow stream. The test results are shown in Figures (4,5). The vortex shedding frequency for this arrangement was

stable and strong over most of the gaps tested. The Euler number had under gone reduction by 20.5%, while the Strouhal number increased by 2.7%. However, the linearity seemed to decrease at low flow ranges for large gaps, when compared with the results for the triangular cylinder only.

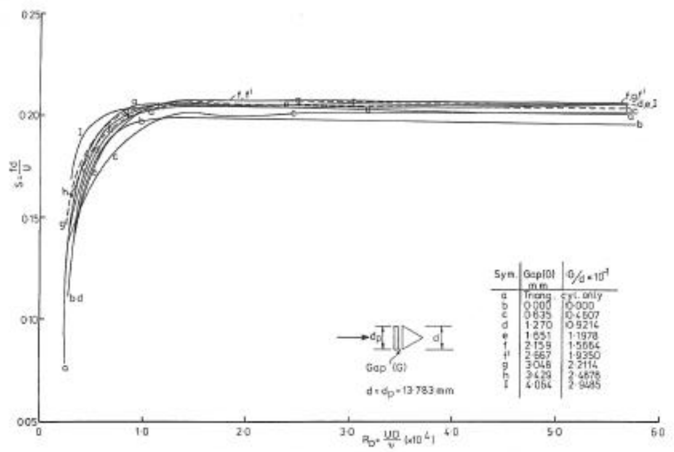


Figure. (4): Strouhal number variation with Reynolds number Arrangement A

2. Arrangement B

In this arrangement, the flat plate is placed behind the triangular cylinder, whose base was facing the flow stream. The results are displayed in Figures (6, 7).

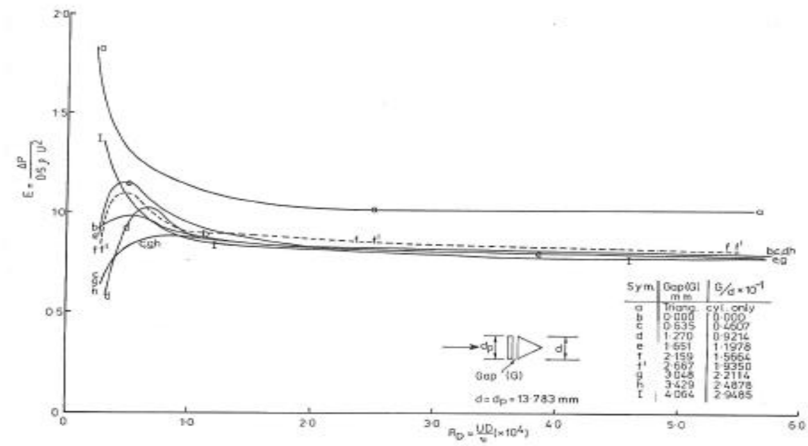


Figure. (5): Euler number variation with Reynolds number Arrangement A

The vortex shedding frequency was highly modulated at Zero gap over the flow range tested, resulting in bad linearity and repeatability. When the gap is increased, the vortex shedding frequency gradually improved and the modulation decreasing. The best gap in this arrangement for strong vortex frequency with minimum modulation and good linearity for $R_D \geq 1\times10^4$ was 4.064.

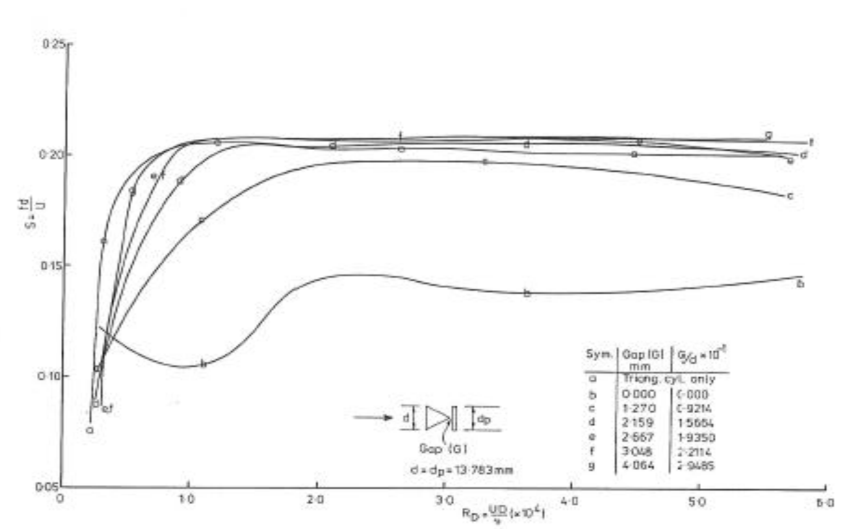


Figure. (6): Strouhal number variation with Reynolds number Arrangement B

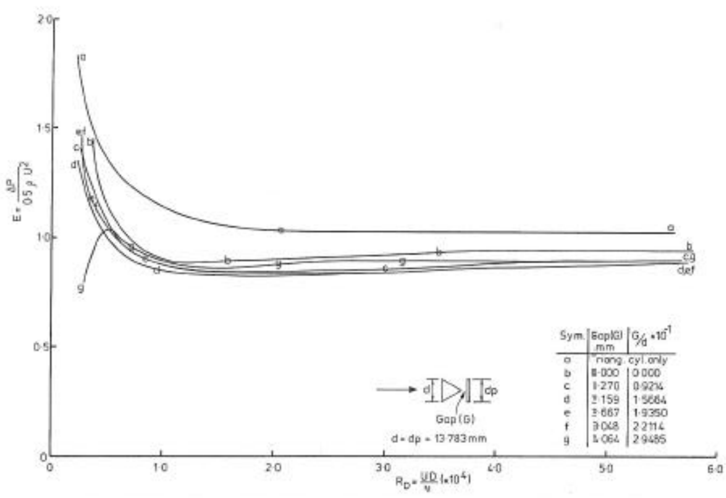


Figure. (7): Euler number variation with Reynolds number Arrangement B

3. Arrangement C

In this arrangement, the flat plate is placed normal to the flow stream, and in front of the apex of the

triangular cylinder. The test results are exhibited in Figures. (8 ,9). The vortex shedding frequency for this arrangement had improved over the whole range of the gap tested, so was the repeatability. The best results were obtained for gap range from 1.905 to 2.159mm. and Reynolds number from 9×10^3 up to 5.9×10^4. The linearity for the meter at these gaps was better than ± 0.24%, the repeatability was better than ± 0.1%, and the pressure loss was lower by 12.9%. These results are considered in comparison with results of a meter utilizing single body results.

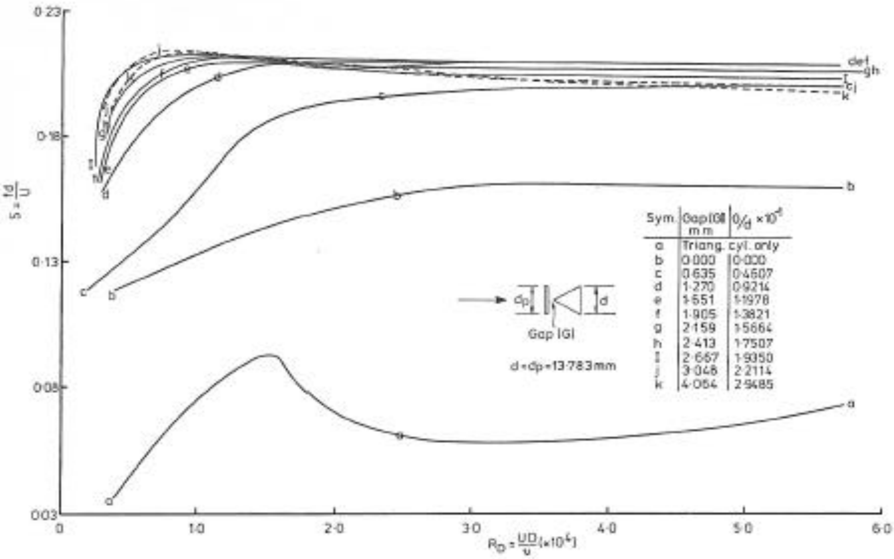


Figure. (8): Strouhal number variation with Reynolds number Arrangement

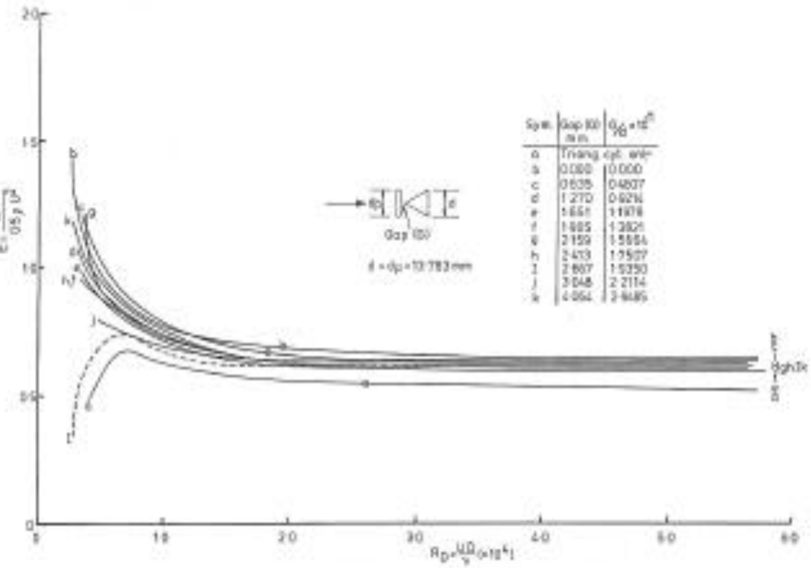


Figure. (9): Euler number variation with Reynolds number Arrangement C

4. Arrangement D

The apex of the triangular cylinder was normal to the flow stream, while the flat plate is placed behind the cylinder base. The test results are shown in Figures. (10, 11). For most gaps, tested at low flow range, the vortex shedding frequency in general (except the zero gap) was unstable and had undergone modulation. At zero gap. the shedding frequency had improved, likewise, the linearity and the repeatability. This is attributed to increase in
Cylinder thickness.

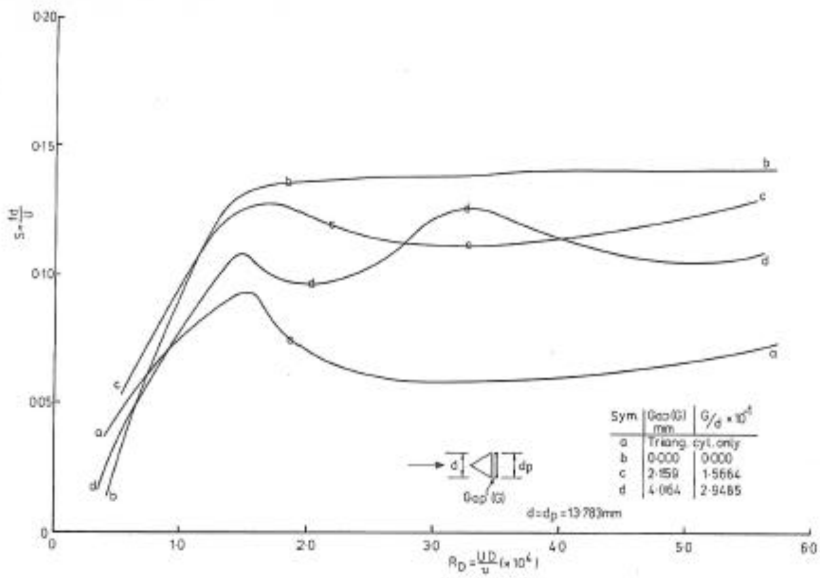


Figure. (10): Strouhal number variation with Reynolds number Arrangement D

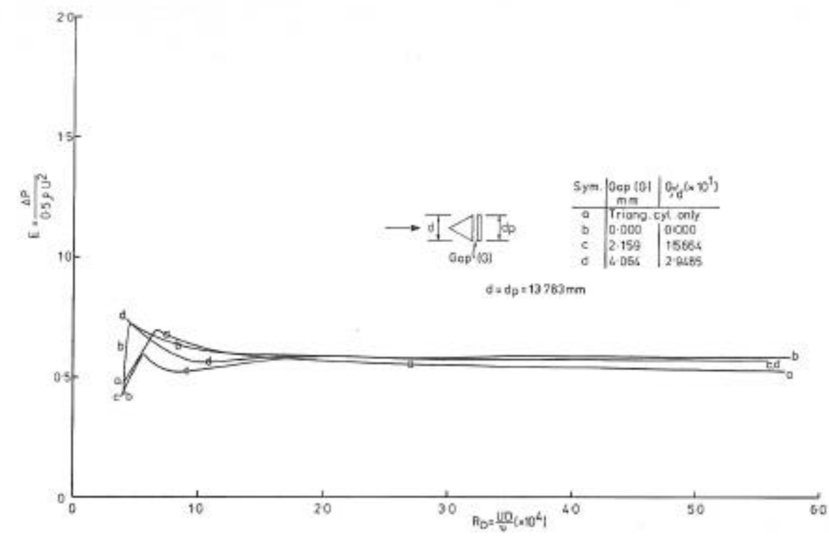


Figure. (11): Euler number variation with Reynolds number Arrangement D

CONCLUSIONS

Experimental results for vortex shedding meters utilizing close tandem bodies have shown better performance, i.e. linearity, repeatability, shedding frequency, lower flow range and lower pressure drop across the meter than for the meters utilizing single bodies. Furthermore, the meter performance indicated dependence on the shape of the bodies, arrangement, position of the cylinder, and gap size. For most arrangements tested, there is an optimum gap size (or optimum G/d) at which the best performance can be achieved, and this occurs always above a critical value of G/d ratio. (G/d gape ratio)

Further work is needed to study the effect of different combination of cylinder shapes and plates, also flow visualization, together with pressure distribution measurement, are recommended to provide a physical understanding of flow around tandem bodies combinations.

REFERENCES

[1] Dr. Ngo Dinh Thinh, Low flow vortex shedding flow meter for hypergolic/all media, 1991 NASA/ASEF summer faculty fellowship program, John F. Kennedy space center, university of central Florida.

[2]AL-JANABI, SABAH J. "Vortex Shedding Air Flow Metering and its Application on a Spark Ignition Engine". Ph.D. Thesis, University of Sheffield, July 1981.

[3] Bence Fenyvesil, Csaba Horath, Investigation on the Non constant Behavior of a Vortex Flow Meter with Narrow Gauge Pipe via Conducting Measurements and Numerical Simulations, Periodical Polytechnic Mechanical Engineering, 61(3), pp. 247-254, 2017

[4] COUSINS, T.,. FOSTER, S. and JOHNSON, P.A. "A Linear and Accurate Flow meter Using Vortex Shedding".Symp. Power Fluidic for Process Control, University of Surry, 1973, pp.45-56.

[5]Lomes, D.J.Vortex Flow Metering Challenges the Accepted Techniques". Control and Instrumentation, Vol.7, No13, 1975.

[6] ZANKER, K.J. and COUSINS, T. "The Performance and Design of Vortex Meters". Conference of Fluid Flow Measurement in the Mid 1970's, N.E.L.

[7] ROSHKO A, "On the Development of Turbulent Wakes from Vortex Stress". NACA TN 2913, March 11953, pp..1-24

[8] M.A.Gallis and J.R.Torcynslci," Effect of slip on vortex shedding from a circular cylinder in a gas" Phy.Rev.Fluid 6, 21june 2021.

[9] M. Reik, R.Hoker, C.Bruzzese,"Flow rate measurement in a pipe flow by vortex shedding" Flow measurement and Instrument, volume 59, March 2018, pp. 88-102

[10] Gong, Y. *et al*. Dual-Mode Fiber Optofluidic Flowmeter With a Large Dynamic Range. Journal of Lightwave Technology 35, 2156–2160 (2017).

[11] Li, Y., Yan, G., Zhang, L. & He, S. Microfluidic flowmeter based on micro "hotwire" sandwiched Fabry-Perot interferometer. *Optics Express* 23, 9483–9493 (2015).