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DEVELOPMENT OF ROBUST VELOCIMETER FOR NATURAL WATER FLOW MONITORING

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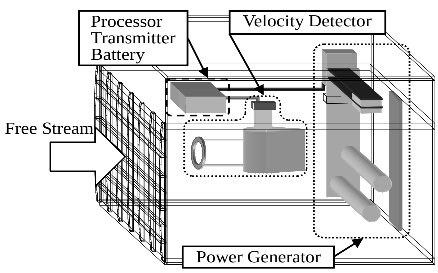
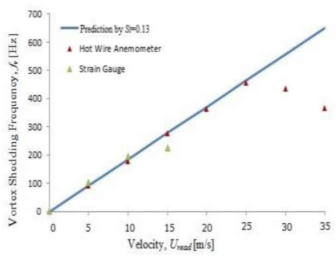
Graphical abstract





Abstract

The ring-velocimeter coupled with a hot wire/film probe was developed and has been applied to wind and water tunnel experiments in Fluids Engineering Laboratory of Nagaoka University of Technology. In this study, the hot-wire/film probe is replaced by a cantilever attached by a strain gauge to detect the drag acting on the ring. The vortex shedding frequency from the ring is determined from the drag fluctuation by applying the spectrum analysis, and the flow velocity in turn since it is proportional with the vortex shedding frequency. This technique for flow velocity measurement is robust in the sense that it is strong against the noise or decay of the detected signal since the dominant frequency is insensitive to such disturbances, and that the detecting probe is strong against the contaminants or particles/objects carried by the fluid. These advantages, together with its simple and cheap characteristics, make it possible to apply to natural water flow with severe conditions.

Keywords: Flow velocimeter, natural water flow, ring, vortex shedding frequency

Abstrak

Satu gelung velocimeter yang digabungkan dengan penderia wayar panas telah dibangunkan dan diaplikasikan dalam eksperimen terowong angin dan air di Makmal Kejuruteraan Bendalir, Universiti Teknologi Nagaoka. Dalam kajian ini, penderia wayar panas telah digantikan dengan menggunakan julur yang dipasang dengan satu tolok terikan untuk mengesan daya seretan yang bertindak pada gelung. Frekuensi "vortex shedding" dari gelung telah terhasil dari variasi daya seretan, dan ia ditentukan dengan menggunakan analisis spektrum dan halaju aliran yang mana ia berkadar terus antara halaju aliran dengan frekuensi "vorteks shedding". Kaedah yang digunakan ini untuk mengukur halaju aliran adalah teguh terhadap bunyi dan pereputan isyarat yang dikesan disebabkan frekuensi dominan yang diperolehi adalah tidak sensitif terhadap gangguan sedemikian, dan penderia pengesan adalah kukuh terhadap bahan pencemar atau zarah mahupun objek yang dibawa sekali oleh bendalir. Kelebihan kaedah ini, selain daripada struktur yang ringkas dan murah membolehkan velocimeter ini dipakai dalam aliran air semula jadi walaupun dalam pelbagai keadaan yang sukar.

Kata kunci: Aliran velocimeter, aliran air semula jadi, gelung, frekuensi "vorteks shedding"

1.0 INTRODUCTION

Since the frequency *fv* of Karman vortex shedding from a cylindrical body immersed in a flow is nearly proportional with the flow velocity *U*, the phenomenon is utilized to measure flow velocity or flow rate [1]. In practical applications, the vortex structure is spoiled at the end of the cylinder and periodicity of vortex shedding becomes lower. When the vortex generating body is torus (ring-shaped), vortex ring free from the end effect as shown in Figure 1 sheds bringing a stable relationship between *fv* and *U* [2][3]. A velocimeter using a ring and hot wire (or hot film for water flow) shown in Figure 2 was developed and has been used in the Fluids Engineering Laboratory of Nagaoka University of Technology (FELNUT), Japan for wind tunnel and water tunnel experiments [4]. Since the velocity *u* at a properly selected point on the axis downstream the ring includes fluctuating component caused by the vortex shedding, its frequency *fv* is determined from the spectrum of *u* detected by the hot wire and then *U* is determined from *fv* in turn.

This ring/HW velocimeter has the following advantages.

1) Its measurable velocity range is extending to very low velocity.
2) It is insensitive to the precision or quality of the original signal *u*, such as decay due to temperature change or the drift of hot wire (or film) velocimeter.
3) Once the relationship between *fv* and *U* has been established, no calibration is required.

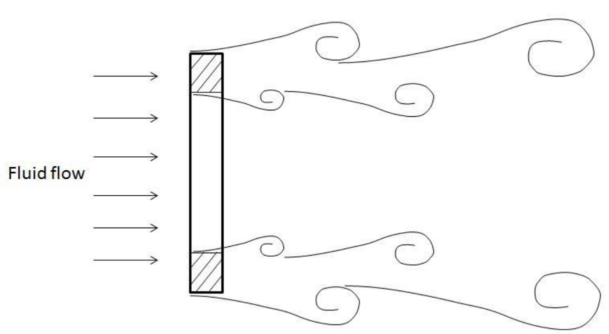


Figure 1 Ring-shape Karman vortex shedding from a torus body

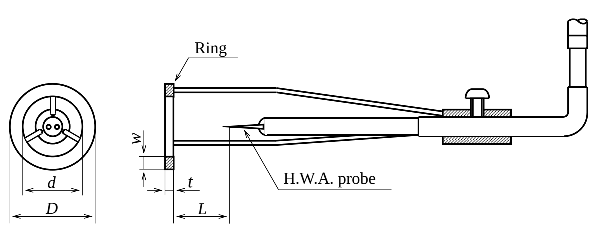


Figure 2 Ring/HW-velocimeter [4]

On the other hand, it is not applicable to natural water flow which carries contaminants or solid particles since the hot wire and hot film probe are fragile and expensive.

Recently, demand for monitoring of river flow is becoming crucial to reduce or to prevent from flood disasters. Hence, a concept of instrument for river flow monitoring with self-power-supply was proposed by FELNUT utilizing the ring velocimeter, as shown in Figure 3 [5]. In the instrument, energy is harvested from vibration caused by the flow itself and the velocity measurement by a hot film in the ring velocimeter is replaced by drag force measurement to make it durable in natural river flow.

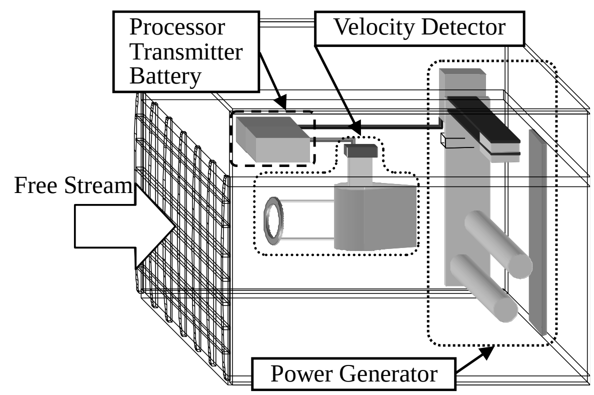


Figure 3 Water flow monitoring instrument proposed by Koide *et al* [5]

The specific aims of this study are to develop a ring velocimeter applicable to natural water flow through the measurement of drag force and to examine its robustness against severe conditions which commonly are existing in natural water flows.

2.0 EXPERIMENTAL

In order to detect the drag force F_D acting on the ring, a strain gauge was attached to the cantilever support of ring as shown in Figure 4, and its effectiveness was tested in uniform and low turbulent flow of water tunnel of FELNUT. Another ring/strain-gauge velocimeter using a geometrically similar ring (X_L-ring) was made and tested using a suction type wind tunnel in Aeronautics Engineering Laboratory of UTM, Kuala Lumpur (AELUTMKL).

To confirm the fluid dynamic similarity and to examine robustness of the ring velocimeter against disturbances of flow field, a ring/HW velocimeter with the identical dimension X_L-ring was tested in the same wind tunnel. Figure 5 shows the experimental set up, instruments and signal analysis system for this wind tunnel experiment.

Specifications of X_L-ring used in this study and rings tested in FELNUT are given in Table 1. The rings are not precisely similar to each other but the aspect ratio scatters over a range $0.714 \leq t/w \leq 0.800$. However, as seen later in Figure 7, the aspect ratio has insignificant influence on the vortex shedding frequency.

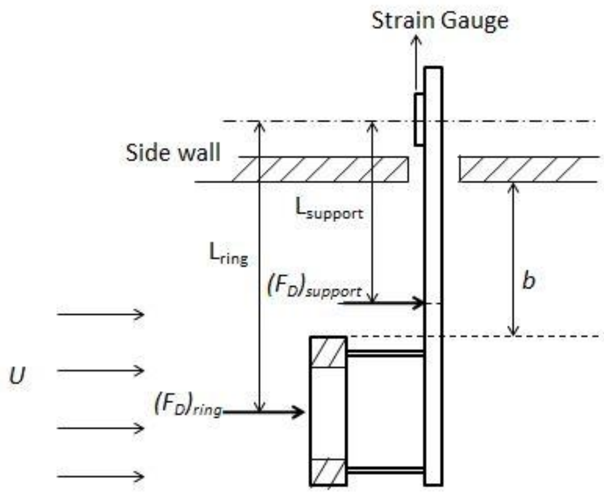


Figure 4 Ring/strain-gauge velocimeter

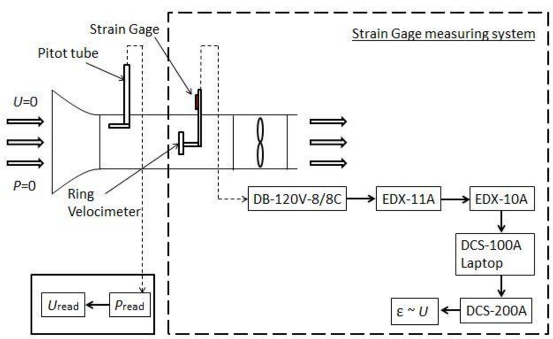


Figure 5 Experimental set up for wind tunnel experiment in Aeronautical Engineering Laboratory, UTM Kuala Lumpur

Table 1 Dimensions of rings. [mm]

	D	*d*	*w*	*t*	*L*	Aspect ratio,
Standard-Ring[4]	19.9	14.4	2.75	2.1	12.0	0.764
S-Ring[4]	10.0	7.0	1.5	1.2	6.0	0.800
A-Ring[4]	19.9	14.4	2.75	2.1	12.0	0.764
L-Ring[4]	40.0	28.8	5.6	4.0	24.0	0.714
X_L-Ring	50.0	36.0	7.0	5.0	30.0	0.714

3.0 RESULTS AND DISCUSSION

Figure 6 shows spectra of drag detected by the ring/strain-gauge velocimeter for varying velocity obtained in water tunnel of FELNUT. A peak is appearing in a spectrum corresponding the vortex shedding. The peak frequency f_D is converted into Strouhal number $St=f_D\ w/U$ and plotted against Reynolds number $Re=Uw/\nu$ in Figure 7, compared with existing St~Re data obtained by ring/HW (or HF for water) [4]. Figure 7 confirms that the peak frequency in the drag spectrum is correlating with the vortex shedding and the dynamic similarity holds between various flows.

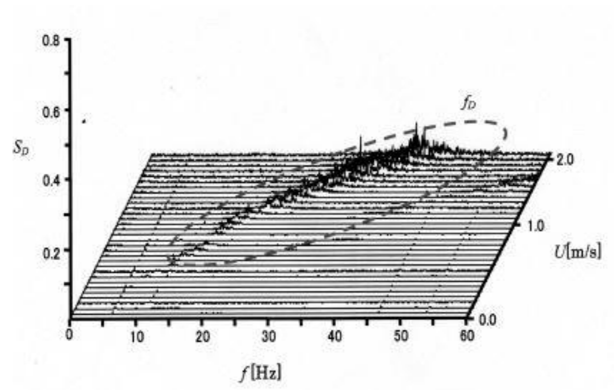


Figure 6 Spectra of drag by ring/strain-gauge velocimeter in water tunnel of FELNUT (X_L-Ring)

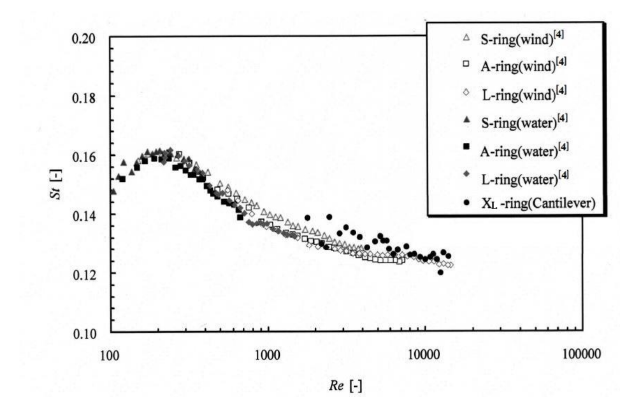
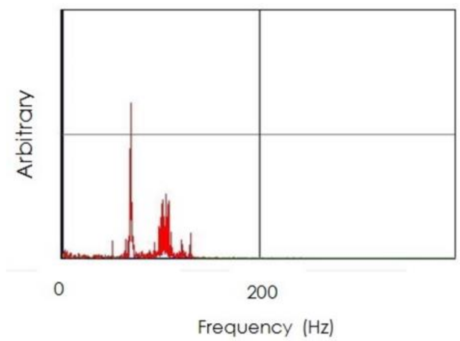
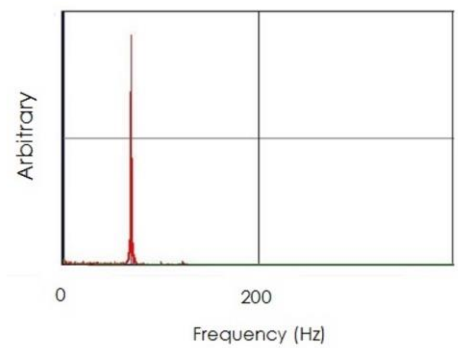


Figure 7 *St* vs. *Re* in water tunnel obtained by ring/stain-gauge velocimeter compared with results of ring/HW and ring/HF

Examples of spectra of F_D obtained by the ring/strain-gauge velocimeter through wind tunnel experiment in AELUMKL are given in Figure 8. When U <10m/s, two peaks are observed in a spectrum as seen in Figure 8 (a). In the spectrum, the highest peak at 70 Hz corresponds to the natural frequency of the ring supporting structure and the lower peak at around 110 Hz is caused by the vortex shedding. At higher velocities, the vortex shedding peak becomes unclear as seen in Figure 8 (b). While, the ring/HW velocimeter shows one sharp peak in a *u*-spectrum when U<25m/s, as seen in Figure 9 (a). At higher velocities, the peak frequency does not give the vortex shedding frequency due to disturbance caused by vibration of ring/support structure (see Figure 9 (b)).

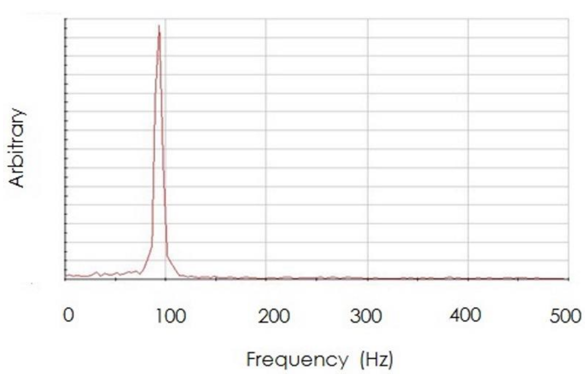


(a) U = 5 m/s

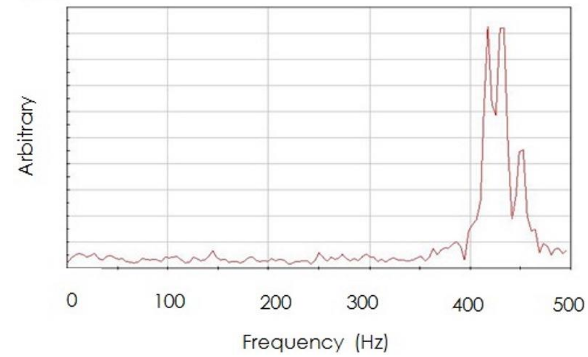


(b) U = 30 m/s

Figure 8 Spectrum of drag detected by ring/strain-gauge velocimeter through wind tunnel experiment in AELUTMKL. (X_L-Ring)



(a) U = 5 m/s



(b) U = 30 m/s

Figure 9 Spectrum of velocity detected by ring/HW velocimeter through wind tunnel experiment in AELUTMKL. (X_L-Ring)

The above vortex shedding frequencies are plotted against *U* in Figure 10, comparing the results obtained by the ring/HW velocimeter and the ring/strain-gauge velocimeter. The straight line is the prediction given by $fv=StU/w$ using $St=0.13$ determined from Figure 7. This value of *St* is equal to that of a square cylinder [6]. It is seen that the two ring velocimeters give the same $fv \sim U$ relationship in the velocity range where the probe support vibration does not affect significantly.

When applying to natural water flows, the defect due to the vibration will be insignificant since the velocity is usually lower than 10 m/s. In addition, the vortex shedding frequency *fv* can be made considerably lower than the natural frequency of the support by using a larger ring and more rigid support.

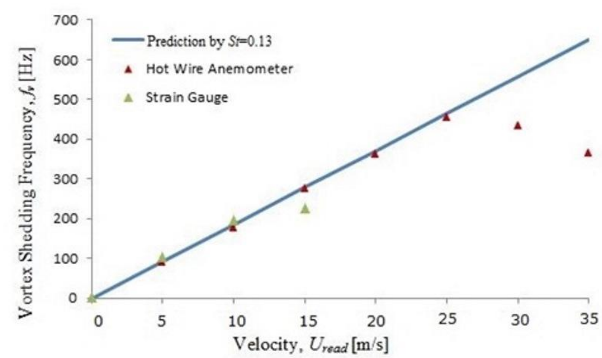


Figure 10 Vortex shedding frequency through wind tunnel experiment in AELUMKL

Since the wall, or free surface, will affect the vortex shedding, influence of the gap between the edge of the ring and wall, *b* in Figure 4, was examined. The vortex shedding frequency *fv* is normalized by the corresponding prediction and plotted against *b/D* in Figure 11. The result shows that the influence of the wall is negligible when the ratio of the gap to the ring outer diameter is larger than $b/D>0.4$ irrespective of velocity *U*.

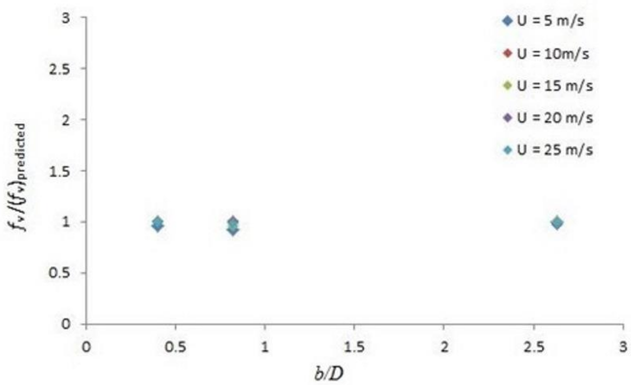


Figure 11 Influence of wall

The directional characteristic is of significance in practical applications since the direction of natural flows is not stable. Hence, the influence of angle of ring axis relative to the flow direction was tested. The result is plotted in Figure 12 compared with that of Koide *et al*. It is seen that the tilting angle θ does not affect the relationship between *fv~U* when $\theta < 18$ degree within the error of 10 % which is acceptable for the natural flow monitoring.

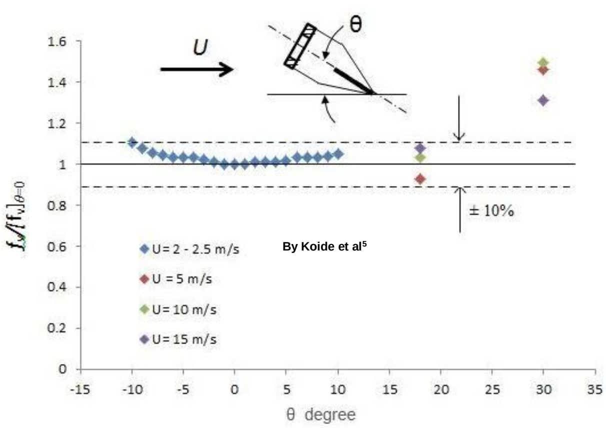


Figure 12 Influence of tilting angle

4.0 CONCLUDING REMARKS

In this study, two identical rings, named X_L-ring, geometrically similar to Standard ring were made in order to confirm the fluid dynamic similarity and to examine robustness of the ring velocimeter. One of the X_L-rings was coupled with a strain gauge to detect the drag force of the ring, and the other was attached to a HWA probe. The former was tested in a water tunnel of Fluids Engineering Laboratory of NUT (FELNUT) and showed that the drag detected by the ring/strain-gauge velocimeter well gives the vortex shedding frequency in water flow.

Then, both of them were tested using a suction type wind tunnel in Aeronautics Engineering Laboratory of UTM, Kuala Lumpur (AELUTMKL).

The dynamic similarity was confirmed for this ring geometry, giving a relationship between the flow velocity *U* and the vortex shedding frequency f_v for arbitrary ring size. The characteristic test showed that the ring velocimeter is robust against two disturbances, the wall (or free surface) and the tilting angle, which usually exist in natural water flow.

The principle of the ring velocimeter is robust against disturbances and noises because of the facts that the f_v~*U* relationship is insensitive to the temperature, property and contaminant of water and that the detecting of f_v is not affected by decay of the signal due to drift of the instrument. It is also mechanically robust because the detector exposed to the flow is the ring and support while the strain gauge is out of flow.

From the view point of practical application, the ring/strain-gauge velocimeter is advantageous due to its simple structure making the cost very low, as compared conventional or recently proposed ones [7][8].

Another advantage of practical importance comes from the fact that no calibration is required for the ring velocimeter since *St*=0.13 can be applied in the practical range of Reynolds number, say *Re* > 1900, within an error of 10 %.

This study shows that the ring/strain-gauge velocimeter is a promising technique to monitor natural river flows at as many points as required to reduce damages of flood disaster.

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