International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:9, No:4, 2015

CFD Effect of the Tidal Grating in Opposite Directions

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Abstract**—**Flow blockages referring to the increase in flow are being considered as a vital equipment for marine current energy conversion. However, the shape of these devices will result in extracted energy under the operation. The present work investigates the effect of two configurations of a grating, convergent and divergent that located upstream, to the water flow velocity. The flow characteristics are studied by Computational Fluid Dynamic simulation by using the ANSYS Fluent solver for these specified arrangements of the grating. The results indicate that distinguished characteristics of flow velocity between "convergent" and "divergent" grating placements is up to 10% in confined conditions. Furthermore, the velocity in case of convergent grating is higher than that of divergent grating.

Keywords**—**Marine current energy, marine current energy converter, turbine grating, RANS simulation, water flow velocity.

I. INTRODUCTION

DEMANDS for the use of renewable energy technologies to generate electricity are growing due to environmental problems such as air pollution, greenhouse effect. Hence, it is necessary to find alternative energy resource to supply world increased energy needs concerning environmental issues. Hydrokinetic energy appears as a good choice for alternative energy source to meet their electricity requirements and be clean, freely available with almost no threat to the environment. The kinetic energy can be converted into a useful form by suggested technologies, for instance into electricity using a conventional horizontal axis or a cross-flow water turbine [1]. In the last decade, the technologies of converting marine current into useful one have undergone rapid growth, and today marine energy is used as an alternative source. The marine energy source has major advantages over other renewable energy resource, as it is more predictable than wind and solar power and has high power density compared to wind energy [2], [3]. Therefore, small marine current turbines will give similar output to wind turbines with bigger diameters. The energy density in a marine stream can be calculated by using (1):

$$P_d = \frac{1}{2}\rho U_0^3 \tag{1}$$

A marine current site provides the amount of hydrodynamic power substantially proportional to the cube of the flow speed. Thus, small variations of flow speed produce very considerable fluctuations of kinetic power extracted from marine current site. However, not all energy available in the marine stream can be extracted by a water turbine. For a stand-alone water turbine, the maximum efficiency is approximately 59% as known by Betz limit [4], [5]. Garrett and Cummins found that the theoretical extractable power from the marine stream could decrease up to 40% if turbines block 90% of the stream area [6]. Therefore, there are several factors that can make improvement for the marine current system. These include the effect of the free surface, the possible occurrence of cavitation, the type of water turbine, and different velocity profiles. The last fact is commonly used for increased flow speed and development of water channel's operational performance [7].

The marine current energy group at the division of Electricity at Uppsala University recently deployed an experimental hydrokinetic energy converter into the river Dalalven in 2013 (Fig. 1) [8]. The aim of the project is to run an experimental power plant under realistic conditions using the stand-alone turbine. The marine current energy converter consists of a vertical axis turbine connected directly to a generator that has been adapted to a slow water motion. The optimal operation of the system is obtained if the power coefficient of turbine is 0.35 at the water velocity of about 1.4 m/s and the efficiency of generator is 86%.

Enhancement of the marine current turbine above for extraction of the kinetic energy of the flowing water can be made by the implementation of various channeling devices or diffusers. Leijon introduced a grating that is located upstream, on both sides of and adjacent to the water turbine, as the improvement regarding water flow velocity [9]. Having a grating upstream the turbine will protect it from floating bodies as well as modify the inflow so that the velocity becomes non-uniform between the grating and the water turbine. The later fact is used for the development of water flow performance.

This paper presents detailed simulation results for two grating configurations with different distances between the central bars. Depending on the water flow direction, the type of grating configuration can be called "converging grating" or "diverging grating". Two-dimensional computational fluid dynamics (CFD) simulations are presented to predict gratings performance and water flow velocity profiles along the grating centerlines are measured. The paper is organized as follows. In Section II, grating geometry is described. Next, CFD numerical model is presented in Section III. Then Section IV is considered computational results. Finally, the conclusions and further works are shown in Section V.

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Fig. 1 Deployment of the energy conversion [8]

II. GRATING GEOMETRY

The aim of the present work is to numerically analyze and compare the hydrodynamic behavior of the grating arranged into two directions with changing the narrow distance (w equals to 1m, 2 m, 3 m) and keeping the same relations of the rest of bars in each side.

The proposed grating is introduced as a channeling device integrated into the water current. The design consists of 14 bars located in upstream on the both sides of and adjacent to a water turbine. The interior of the bars network is shaped to form a variable section of the open channel that helps to increase flow speed. The main dimensions of a single bar are listed in Table I where notations are denoted in Fig. 2 (a).

Two grating arrangements, converging and diverging, make a distinction concerning non-uniform velocities of the open channel along the grating centerline. In the first case, the granting is placed in the converging direction, so that the incoming water goes around the grating and the large part of the incoming water reaches the turbine (Fig. 2 (b)). In the second case, the grating is placed in the diverging direction, so that the flow is guided by the grating towards the turbine (Fig. 2 (c)).

TABLE I
GRATING FEATURES

Symbol	Quantity	Specification
b	bar length, i.e. distance between the leading and the tail points of the bar	400 mm
k	bar width	60 mm
φ	angle between bar and horizontal axis	60^0
g	distance between the tail point of a bar and the tail point of the next bar.	200 m
w	distance between central bars	1 m, 2 m, 3 m
n	total number of bars	14

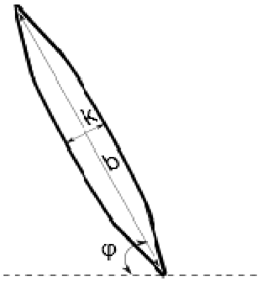
III. CFD NUMERICAL MODEL

The process of generating the 2D CFD is done by the ANSYS Workbench multi-physics platform where it is possible to develop a workflow, starting from CAD generation to post-processing of the results. The Finite Fluent Solver is used in RANS version to solve the Navier-Stoke equations and capture the non-linear values like the continuous change in the water flow around the grating. The procedure for CFD simulations is adjusted in a way, such that the narrow width w between two sides of grating has gradually been increased for numerical purposes. With each value of w (1 m, 2 m, 3 m), the velocity profiles at the centerline of grating are computed for two grating arrangements.

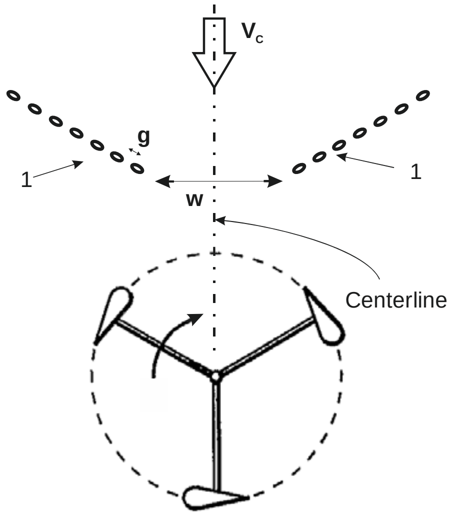
Generating the right computational domain for a Fluid Dynamic problem is an important task of the modeling process. It is necessary to take into account different requirements [10]. First, the domain should not be too small to correctly reproduce the flow around the grating and it should not too large to not uselessly increase cells number of the grid and hence computation time. Second, it has to be considered the requirements of the mesh in terms of quality and cells positioning near the grating.

Some tests are performed to achieve the optimal compromise for both cases. The dimensions of the domain are optimized for the converging arrangement and then the same criteria are applied to the diverging arrangement (Fig. 3). The entire domain has two separated sub-domains in the same plane as the approaching water flow stream in order to obtain the denser mesh around the grating area. To avoid the wall effects to grating, the stationary rectangular domain of 400 m in crossflow width and 500 m in streamwise length is designed to test model. The grating is placed 420 m from the outlet to properly reproduce the wake effect.

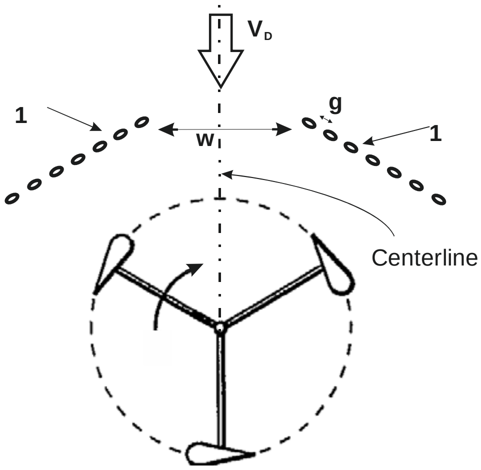
Following boundary conditions are applied also. The stationary domain has a free stream velocity. The hydrodynamic pressure conditions are applied and the initialization is done. The left and the right side is inlet and outlet, respectively using default boundary conditions in simulation software. Inlet requires the speed of inlet velocity of water 1 m/s and at the outlet atmospheric pressure (equal to 101.325 kPa) is set. The top and bottom boundaries of the channel and the bar surfaces are enabled as a “wall” condition. This condition enables the calculation of properties such as velocity and pressure on the surface. Due to low velocities in the flow under study, density variation is negligible and water is treated as incompressible.



(a)



(b)



(c)

Fig. 2 (a) Single bar of grating, (b) diagram of the grating 1 located in converging direction, (c) that of in diverging direction

The standard k-epsilon model is employed and the COUPLED algorithm is selected for pressure correction equation. A second-order spatial discretization algorithm is used for all the equations (pressure, momentum and turbulence) it is well known that that these second order algorithms lead to best results because they considerably reduce interpolation errors and false numerical diffusion [11]. The computational domain is discretized using two-dimensional unstructured mesh (quad mesh). To obtain high quality the two domains (channel and grating) are meshed in different size (Fig. 4). The comprehensive mesh independence study is performed prior to the test series. With the various model conditions, the geometry of the grating is changed and accordingly different meshes are generated to each condition.

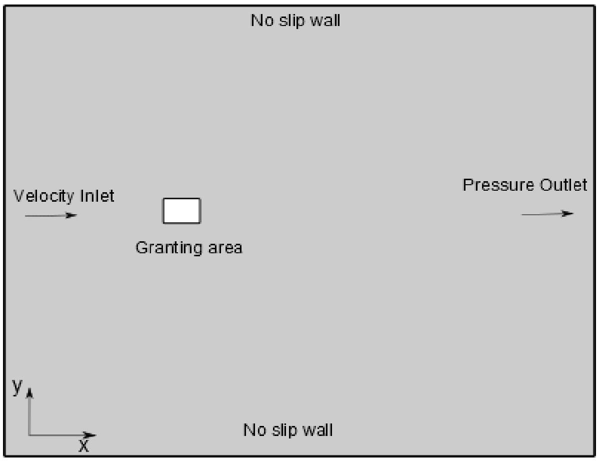


Fig. 3 Computational domain

IV. COMPUTATIONAL RESULTS

The simulation results are presented as factors for the water flow velocity along the grating centerline. The upstream grating has a certain effect on the velocity profile of the water flow. Turbulence is locally appeared by affecting of the grating bars in the main flow direction. By arranging the grating such that it guides the water flow, the water can be managed so that it has a higher velocity in the parts of the grating where the contribution to the power generation is higher and vice versa. The simulations show the characteristics of velocity in two arrangements of grating and compare to each other. The protective effect of the grating arrangement is improved since the turbine thereby will be more encapsulated. The relative velocity of the incident flow is obtained by changing the value of w in different models, converging and diverging.

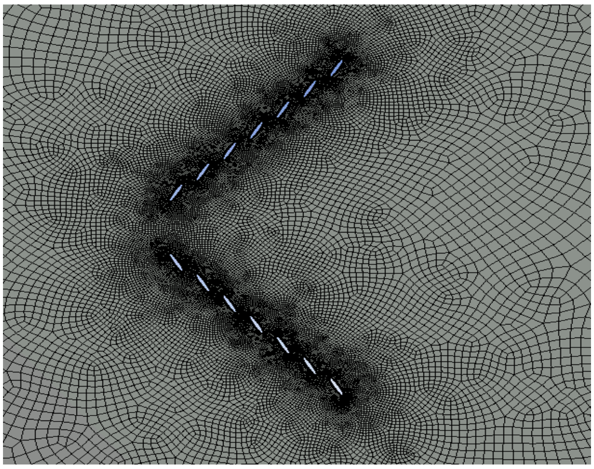


Fig. 4 An example of computational domain mesh w=1.3 m

Figs. 5-8 indicate that the velocity relative to the distance along channel starting from the grating position.

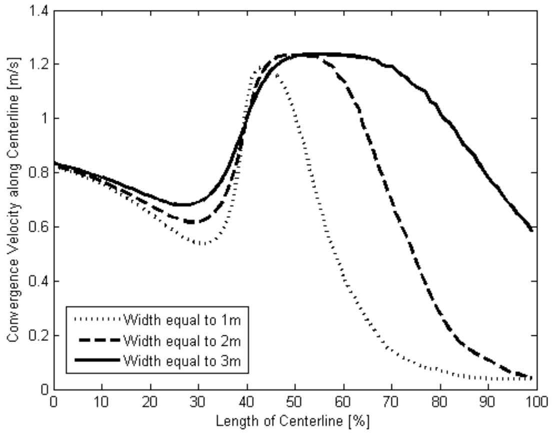


Fig. 5 Velocity profile for the converging grating arrangement

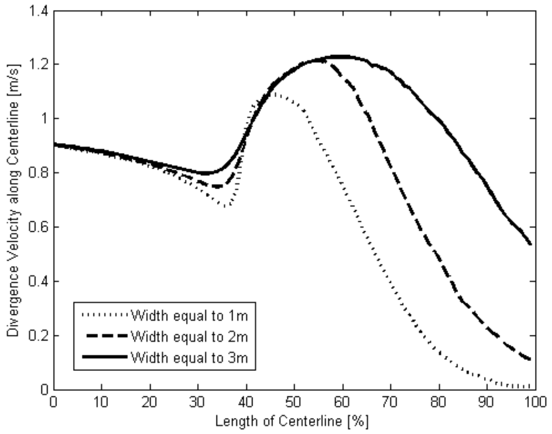


Fig. 6 Velocity profile for the diverging grating arrangement

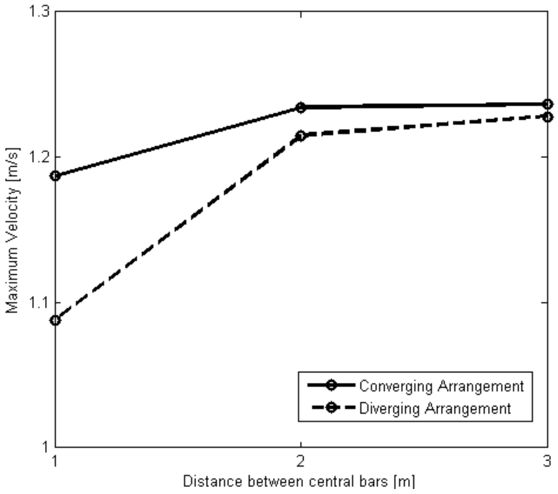
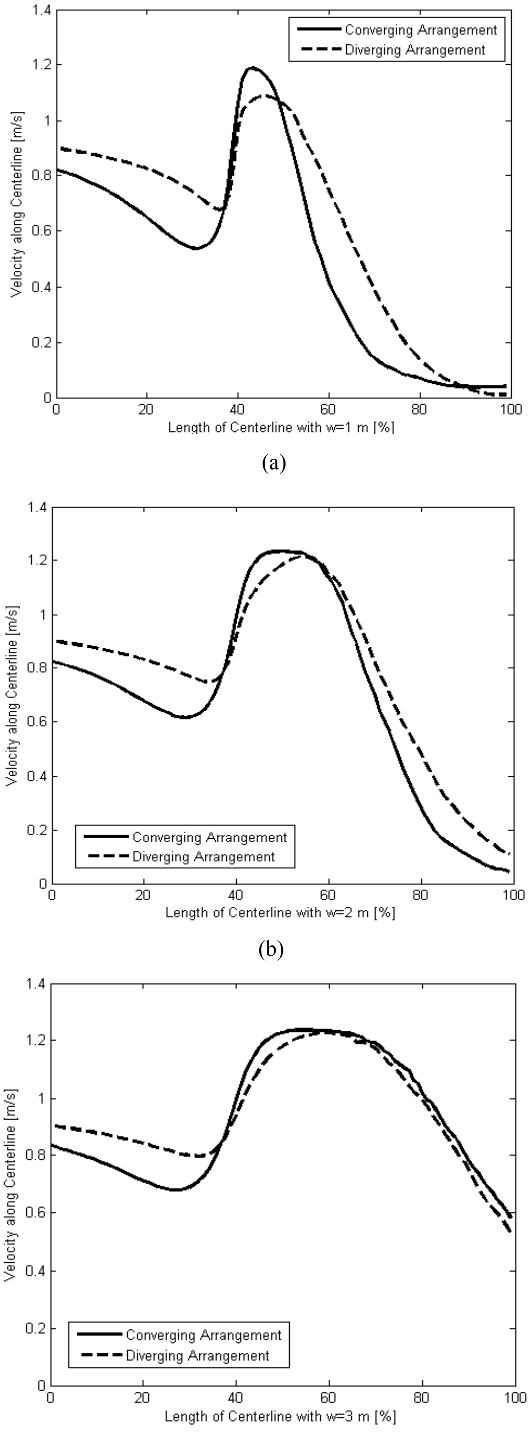


Fig. 7 Maximum value of flow velocity on the grating centerline

Fig. 5 illustrates the velocity profiles along the grating centerline for the converging arrangement with the narrow width was a parameter. The maximum value found for the narrow passage (w=3 m) is 1.24 m/s and it decreases as the passage width with decreases. Its location moves downstream as the passage become wider. For all narrow widths investigated here, the flow velocity is smaller than one along the larger part of centerline, indicating that the grating provide shelter to these locations from the flow.



(a)

(b)

(c)

Fig. 8 Velocity profile for two arrangements, converging and diverging

Fig. 6 displays velocity profile for the diverging arrangement. Similar to the converging arrangement, the maximum values are quite lower (1.23 m/s with w=3 m). As for the diverging arrangement, the maximum value decreases and its location moves further downstream with increasing narrow width.

Fig. 7 presents the maximum values of water velocity along the grating centerline all grating arrangements, as a function of narrow widths. For all values w, the flow velocity for converging grating arrangement is considerably larger than for the diverging arrangement. For w=3 m, a similar conclusion holds, for smaller values w=1 m, 2 m the maximum velocity in converging arrangement clearly becomes very larger than the value in the diverging arrangement (10% at w=1 m).

Fig. 8 display a summary of the results for all narrow width and grating investigated. The characteristic of velocity is non-monotonic, the curve slope changes significantly. The flow at the upstream is uniform for velocity equal to 1 m/s then speed up at central bars and speed down at the downstream in both arrangements. For two values w =1 m and w=2 m, the velocity profile for converging placement is higher than for diverging placement around the middle grating centerline, but its extent is quite less than that of it. This is logical because the diverging shape of grating does not catch the flow, as opposed to the converging shape.

V. CONCLUSIONS AND FURTHER WORK

Simulation results of velocity profile in passage between converging and diverging grating arrangements have been made to a provide insight in the related flow. The water flow velocity is non-monotonic around the area the grating placed. The maximum water flow velocities in the converging and diverging passage were found to increase monotonically with increasing narrow width. The distinction of flow velocity in the convergent grating placement is greater than the divergent with up to 10%. The results indicate that the simulation outcomes can offer a good guidance for the grating development, even though the difference between the simulation and experimental results is fairly large.

This study was limited to two grating arrangements and was conducted with a given inflow. Further investigation is needed to expand the validity of the present findings.

ACKNOWLEDGMENT

The present research is financially supported by Uppsala Municipality, CFE-III, Uppsala University, STandUP for Energy, Ångpanneförening Research foundation, J. Gust. Richert Foundation.

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