Research & Reviews

Research and Reviews: Journal of Engineering and Technology

Experimental Study of the Internal Overlap Ratios Effect on the Performance of the Savonius Wind Rotor

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Article

Received: 27/08/2012
Revised: 23/09/2012
Accepted: 28/09/2012

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Key words: Savonius rotor, internal recovery, global characteristics, experimental results, wind tunnel, power, energy.

ABSTRACT

In this paper, experimental investigations are carried out to study the internal overlap ratios effect on the performance of a Savonius wind rotor at different Reynolds numbers. To do this, an open wind tunnel has been designed and realized in Laboratory of Electro-Mechanic Systems at National School of Engineers of Sfax. This involved also the instrumentation and the necessary equipments for the global characterization of the vertical axis wind turbines. Particularly, this research required the setting up of four mounting characterized by the internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$. The overall performance evaluation of the rotor has been based on the power and dynamic torque coefficients.

INTRODUCTION

In a typical wind turbine design there are numerous design variables that must be considered in order to optimize the power output for a given wind regime. A typical Savonius design consists of two vertical blades aligned with the rotating shaft. When compared with other wind turbine the Savonius wind rotor offers lower performance in terms of power coefficient. Indeed, it offers a number of advantages as it is extremely simple to build, it is self-starting and it has no need to be oriented in the wind direction. Although it is well suited to be integrated in urban environment as mini or micro wind turbine it is inappropriate when high power is requested. For this reason several studies have been carried-out in recent years in order to improve its aerodynamic performance [1-7]. Particularly, D'Alessandro et al [1] developed a mathematical model of the interaction between the flow field and the rotor blades. The aim of there research was to gain an insight into the complex flow field developed around a Savonius wind rotor and to evaluate its performance. They validated the model by comparing it with data obtained at Environmental Wind Tunnel (EWT) laboratory of the "Polytechnic University of Marche". Altan et al. [2] introduced a new curtaining arrangement to improve the performance of Savonius wind rotors. The curtain arrangement was placed in front of the rotor preventing the negative torque opposite the rotor rotation. The geometrical parameters of the curtain arrangement were optimized to generate an optimum performance. The rotor with different curtain arrangements was tested out of a wind tunnel, and its performance was compared with that of the conventional rotor. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. The experimental results showed that the performance of Savonius wind rotors could be improved with a suitable curtain arrangement. Irabu and Roy [3] improved and adjusted the output power of Savonius rotor under various wind power and suggests the method of prevention the rotor from strong wind disaster. In this study, as the appropriate device to achieve the purpose of it, a guide-box tunnel was employed. The guide-box tunnel is like a rectangular box as wind passage in which a test rotor is included. At first, the experiment was conducted to find the adequate configuration which would provide the best relative performance. The experiment, however, does not include the test to retain the guide-box tunnel from the strong wind. The experiments include the static torque test of the fixed rotor at any phase angle and the dynamic torque test at rotation of them. Consequently, it was found that the maximum rotor rotational speed was achieved in the range of the guide-box area ratio between 0.3 and 0.7 and the value of the output power coefficient of the rotor with guide-box tunnel of the area ratio 0.43 increases about 1.5 times with three blades and 1.23 times with two blades greater than that without guide-box tunnel, respectively. It seemed that the performance of Savonius rotor within the guide-box tunnel is comparable enough with other methods for augmentation and control of the output. Saha et al. [4] conducted wind tunnel tests to assess the aerodynamic performance of single, two and three-stage Savonius rotor systems. Both semicircular and twisted blades have been used. A family of rotor systems has been manufactured with identical stage aspect ratio keeping the identical projected area of each rotor. Experiments were carried out to optimize the different parameters like number of stages, number of blades and geometry of the blade. A further attempt was made to investigate the performance of two-stage rotor system by inserting valves on the concave side of blade. Fujisawa [5] investigated the flow fields in and around Savonius rotors at various overlap ratios to clarify the effect of overlap on the flow mechanisms. Measurements of phase-averaged velocity distributions were carried out using particle imaging velocimetry with a conditional sampling technique, and the results were compared with numerical calculations by a discrete vortex method. The measured velocity distributions indicate clearly the effect of the overlap both on the flow through the overlap and on the formation region of the vortices downstream of the rotor. Although numerical calculations can predict the basic features of the variation of the flow field with rotor angle, the flow field of a stationary rotor, especially at small rotor angles, is not well reproduced in the calculations, suggesting that the assumptions of flow separation at the tips of the blades and the two-dimensionality of the flow are invalid. However, the correlation with measurement is improved for the flow over a rotating rotor. Al-Bahadly [6] determined and designed a suitable wind turbine which could be employed for rural homes or other small-scale applications. A variety of horizontal and vertical axis wind turbines exist, each possessing a number of advantages and disadvantages which needed to be taken into account before a basis for the design is selected. A small robust design which is relatively simple and cheap to construct is in essence the main criteria for wind turbine selection. A Savonius type rotor, which is a rotor based on a modification of the ‘S’ rotor, is selected as it best fitted the design criteria. A small prototype 1.5 m tall with a rotor diameter of 0.65 m is designed and built. The finished prototype is used to estimate the power obtainable under normal operating conditions. Dobrev and Massouh [7] used CFD to study the behavior of a Savonius wind turbine under flow field conditions and to determine its performance and the evolution of wake geometry. The flow analysis helps to qualify the design of the wind turbine. They are making an experimental investigation in wind tunnel using PIV to validate simulations. There’s investigation permits to determine the structure of the real flow and to access the quality of numerical simulations. Damak et al. [8] studied the aerodynamic behaviour of the helical Savonius rotors installed in an open jet wind tunnel. Tests determined the aerodynamic characteristics of the wind turbine. Particularly, they are interested to the power coefficient and the torque coefficient. Driss and Abid [9] studied the aerodynamic characteristics on an open circuit tunnel. They are interested to verify that the test vein provides a uniform out flow, a high-speed and a low-turbulence. The comparison between the numerical results and the global experimental results confirms the validity of the numerical method [10,11].

On the bases of these studies, evaluation of the Savonius wind rotor performance has been reported based on the average produced power and exerted torque in the case of different internal overlap ratios.

Savonius Wind Rotor

Savonius rotor is a vertical axis wind turbine. It is constituted by two half-cylindrical buckles characterized by the diameter d=100 mm and the height H=300 mm. They are collected on a common axis and are fixed within screws to make an angle equal to 180° (Figure 1). Therefore, the position between the two buckles is defined by the longitudinal and transversal distances designed by e and r_s. By introducing the shaft diameter e'=10 mm, the internal overlap ratio r_{pi} is defined as follows:

$$r_{pi}=(e-e')/d \qquad (1)$$

The study of the internal overlap ratios effect on the Savonius rotor characteristics requires the e distance change. This research requires the setting up of four mounting characterized by the internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$ (Figure 2).

MATERIAL AND METHODS

In this study, the rotor axis has been placed in the middle of the wind tunnel test vein having a cross section area of 400 mm x 400 mm. By changing the rotation frequency of the vacuum cleaner SV0081C5-1F type, the wind tunnel exit-air velocity was controlled. The entire tests have been conducted within a hot wire anemometry AM-4204 model to measure the air velocity. In the test vein, the maximum air velocity value is equal to 12.7 m/s. The rotational speed of the wind turbine rotor was measured with a digital tachometer CA-27 model. To measure the static torque on the rotor shaft, a torque meter TQ-8800 model has been used. The dynamic torque exerted on the rotor shaft was measured with a DC generator which transforms the torque on its axis at an electrical current. For that the generator, coupled to the dynamometer RZR-2102 model, display simultaneously the shape speed and the dynamic torque. This dynamometer has been used to provide mechanical power to the generator which delivers an electric current in a resistive load as shown in figure 3.

RESULTS AND DISCUSSIONS

In this investigation, the power and the torque of Savonius rotor were measured for different air flow regimes. From these measures, the power and the torque coefficients were deduced in function of the specific speed λ. These global characteristics are presented for different internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$ and for different wind speed values equal to V=8.8 $m.s^{-1}$, V=9.95 $m.s^{-1}$, V=11.15 $m.s^{-1}$ and V=12.25 $m.s^{-1}$. In the case of the wind speed equal to V=8.8 $m.s^{-1}$, the corresponding values of Reynolds number were calculated for the different internal overlap ratios. These values are respectively equal to Re=121000, Re=114000, Re=108000 and Re=102000. The decrease of Reynolds number values is due to the decrease of the Savonius rotor diameter when the internal overlap ratio between the two buckles increases.

Power

Figure 4 presents the variation of the power depending on the specific speed λ of the Savonius rotor for different internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$ and for different wind speed values equal to V=8.8 $m.s^{-1}$, V=9.95 $m.s^{-1}$, V=11.15 $m.s^{-1}$ and V=12.25 $m.s^{-1}$. According to these results, it’s noted that the gotten curves present a parabolic pace. Therefore, these results show that the internal recovery value has an effect on the presentation of the power values. Globally, it’s noted that the Savonius rotor power reach the most important values for the internal overlap ratio equal to $r_{pi}=0$. With the increase of the internal overlap ratio, a progressive decrease of the power values is observed. For the considered case, it’s noted that the maximal value of the power is equal to P=7.8 W. It is obtained with an internal overlap ratio equal to $r_{pi}=0$ and a specific speed equal to λ=0.39. However, for the overlap ratio $r_{pi}=0.3$, the maximal value of the power becomes equal to P=4.6 W and for a specific speed λ=0.353. For the other cases, these observations could be generalized.

Power coefficient

Figure 5 presents the variation of the power coefficient Cp depending on the specific speed λ of the Savonius rotor for different internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$ and for different wind speed values equal to V=8.8 $m.s^{-1}$, V=9.95 $m.s^{-1}$, V=11.15 $m.s^{-1}$ and V=12.25 $m.s^{-1}$. According to these results, it’s noted that the gotten curves present a parabolic pace. Therefore, these results show that the internal overlap ratio has an effect on the presentation of the power coefficient values. Globally, it’s noted that the Savonius rotor power coefficient reachs the most important values for the internal overlap ratio equal to $r_{pi}=0$. With the increase of the internal overlap ratios, a progressive decrease of the power coefficient values is observed. For the considered case, it’s noted that the maximal value of the power coefficient is equal to Cp=0,324. It is obtained with an internal overlap ratio equal to $r_{pi}=0$ and a specific speed equal to λ=0.392. With the increase of the internal overlap ratio, it’s noted that the extreme characteristics values decrease. Particularly, for the internal overlap ratio $r_{pi}=0.3$ the maximal value of the power coefficient becomes equal to Cp=0.23 for a specific speed equal to λ=0.35.

Dynamic torque coefficient

Figure 6 presents the variation of the dynamic torque coefficient C_{Md} depending on the specific speed λ of the Savonius rotor for different internal overlap ratios equal to $r_{pi}=0$, $r_{pi}=0.1$, $r_{pi}=0.2$ and $r_{pi}=0.3$ and for different wind speed values equal to V=8.8 $m.s^{-1}$, V=9.95 $m.s^{-1}$, V=11.15 $m.s^{-1}$ and V=12.25 $m.s^{-1}$. According to these results, it’s noted that the gotten curves present a parabolic pace. Therefore, these results show that the internal overlap ratio has an effect on the presentation of the dynamic torque coefficient. Globally, it’s noted that the dynamic torque coefficient reaches the most important values for the internal overlap ratio value equal to $r_{pi}=0$. With the increase of the internal overlap ratios, a progressive decrease of the dynamic torque coefficient is observed. For the considered case, it’s noted that the maximal value is equal to $C_{Md}=0.827$. It is obtained with an internal overlap ratio equal to $r_{pi}=0$ and a specific speed equal to λ=0.392. With the increase of the internal overlap ratio, it’s noted that the extreme characteristics values decrease. Particularly, for the internal overlap ratio $r_{pi}=0.3$ the maximal value of the dynamic torque coefficient becomes equal to $C_{Md}=0.62$ for a specific speed equal to λ=0.353. For the other cases, these observations can be generalized.

CONCLUSION

In this paper, the global characteristics of the Savonius rotor with different internal overlap ratios are studied. Particularly, the overall performance of the rotor based on the power and exerted torque has been evaluated. Results conclude that the internal overlap ratio has an effect on the presentation of the global characteristics. Particularly, it’s clear that the power and the torque coefficients reach the most important values for the internal overlap ratio equal to $r_{pi}=0$. With the increase of the internal recovery values, a progressive decrease of the power values is observed at the same specific speed λ.

In the future, we propose to develop an experimental investigation within a particle image velocimetry laser (PIV) system for a finer survey of the local out-flow features.

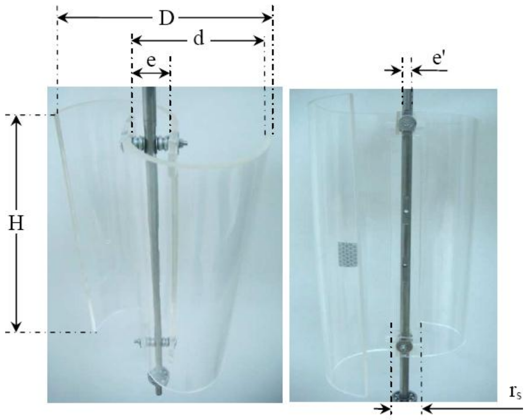


Fig. 1 Geometrical Arrangement

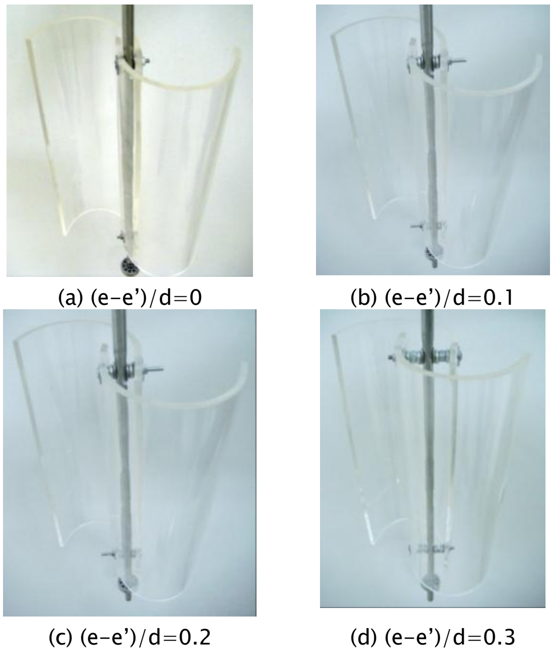
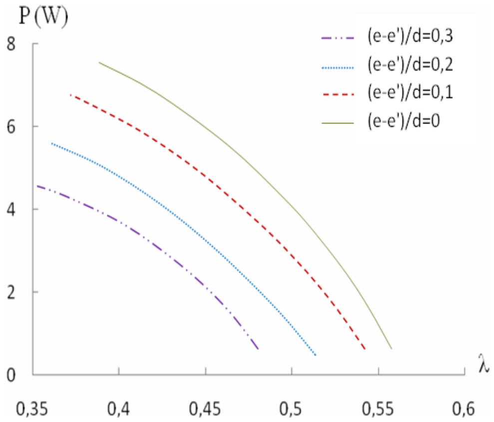
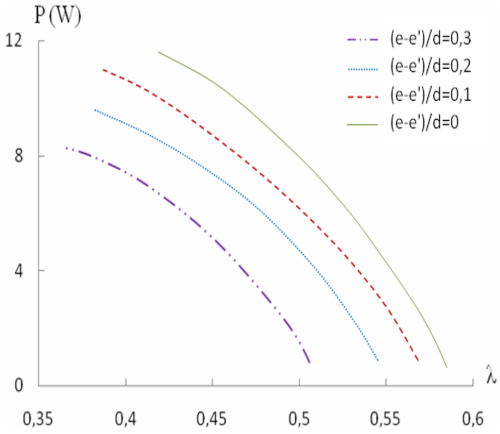


Fig. 2 Different internal overlap ratios

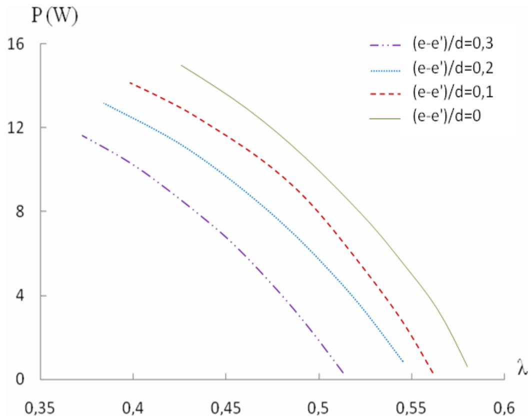
Fig. 3 Wind tunnel equipped by Savonius rotor coupled to the dynamometer RZR-2102 model



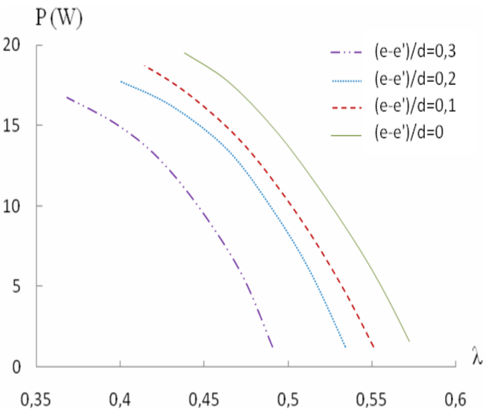
(a) V=8.8 m.s⁻¹



(b) V=9.95 m.s⁻¹

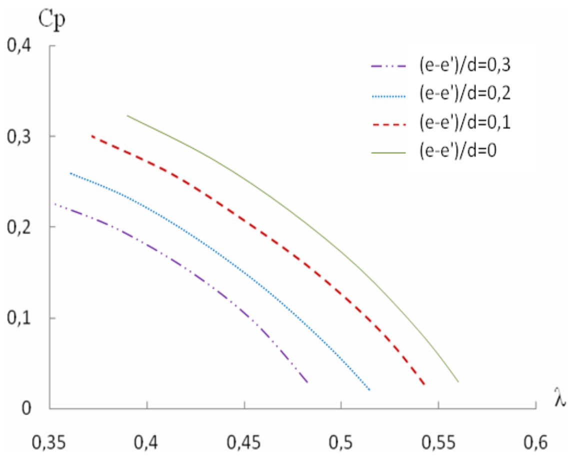


(c) V=11.15 m.s⁻¹

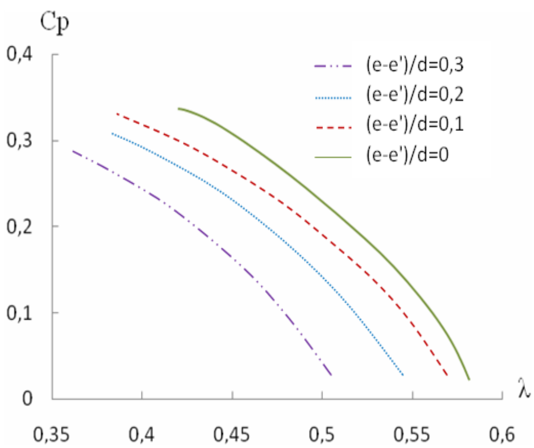


(d) V=12.35 m.s⁻¹

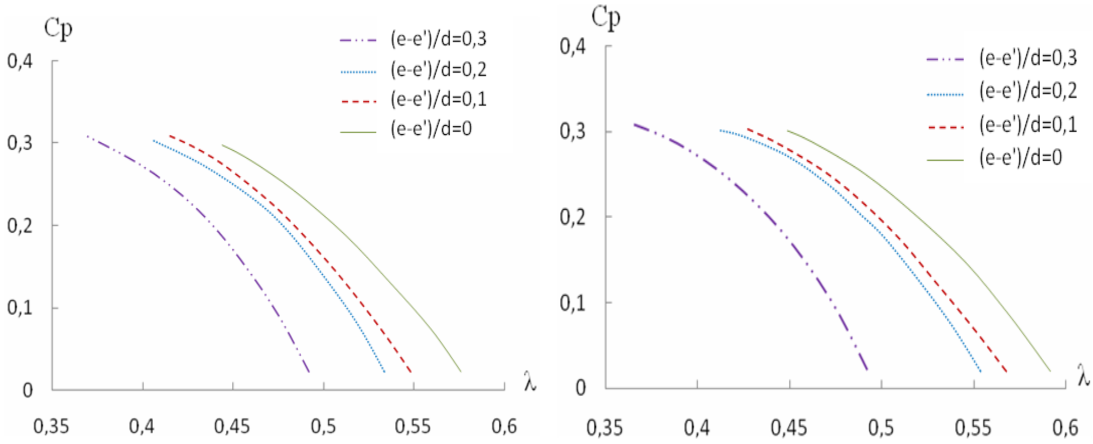
Fig. 4 Variation of the power



(a) V=8.8 m.s⁻¹

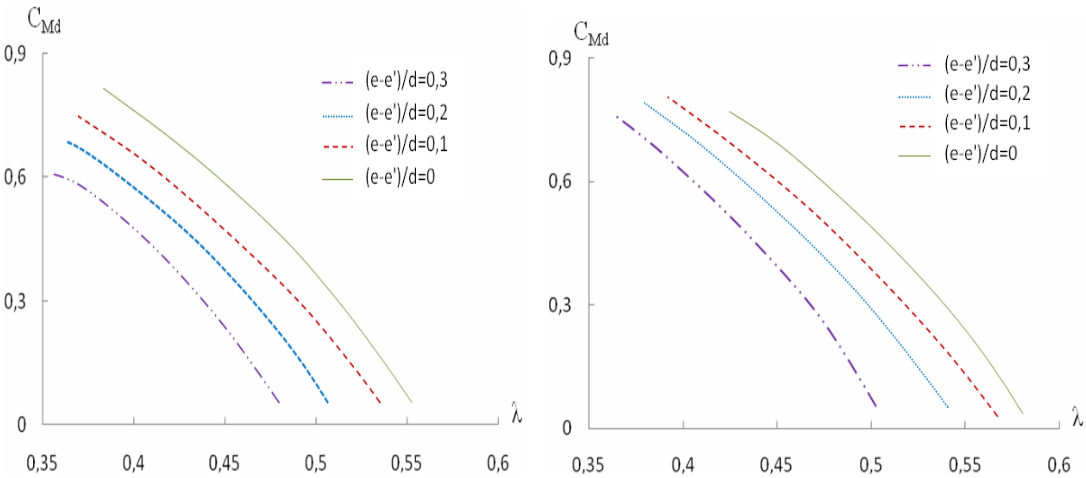


(b) V=9.95 m.s⁻¹

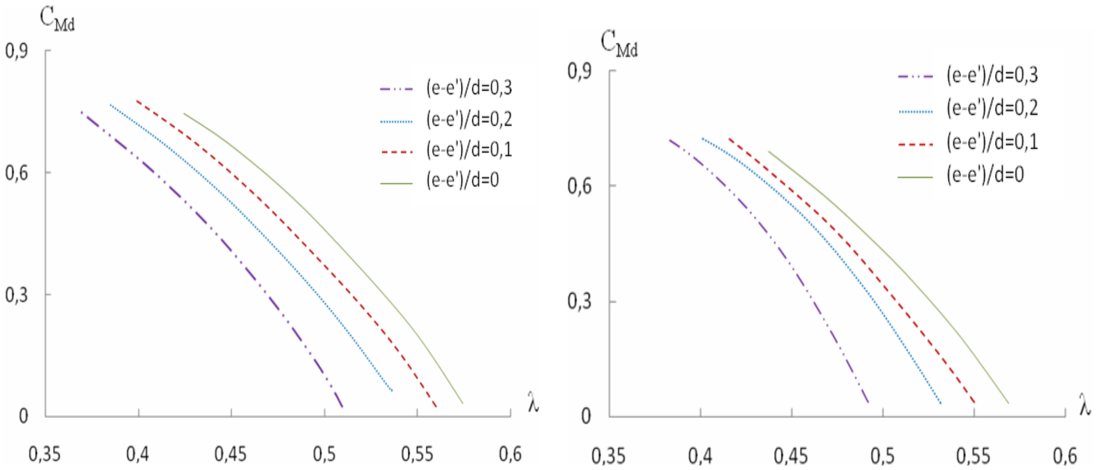


(c) V=11.15 m.s-1 (d) V=12.35 m.s-1

Fig. 5 Variation of the power coefficient



(a) V=8.8 m.s-1 (b) V=9.95 m.s-1



(c) V=11.15 m.s-1 (d) V=12.35 m.s-1

Fig. 6 Variation of the dynamic torque coefficient

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