A STUDY OF BLDC MOTOR GREEN POWER SHIP

Wei-Yuan Dzan

National Kaohsiung Marine University Department of Naval Architecture

No.142, Haijhuan Road,Nanzih District,Kaohsiung 81157,Taiwan,R.O.C.

e-mail: dwydanel@mail.nkmu.edu.tw

Abstract: - This paper primarily probes into the practical value of BLDC (Brushless DC) Motor in green power ships, approaching the comparison between DC and BLDC Motor. This research discusses the advantages of BLDC Motor, introducing its action principles and characteristics, and regards it as one of the essential points of green power ship design, followed by using the PWM method as the preliminary study of the control system.

Key words: Green, Power, Ships Mathematical operator

1 Introduction

In recent years yachts and green power technology are greatly enhanced, plus the appreciation of environmental protection and leisure tourism from society, the research and development of green power ships possesses great economic benefits, and there are many advanced countries engaged in this relevant development. However in order to combine the green power with ship building, BLDC Motor plays an important role. Because the DC Motor's contact-less rectifier structure does not produce any commutation division wear, and the motors can be encapsulated with watertight method, it has more advantages than the traditional DC motors. BLDC Motor will become a major trend of the green power ships application. [1]

2 Actuation Principles of DC Motor

1. The principle of motor rotation is based on the Fleming's left hand rule - a conducting wire is placed in a magnetic field, when there's current through the wire, the wire will cut the magnetic field to cause the movement of itself.

2. When the current goes into the coil and creates a magnetic field, the device applying the currant's magnetic effect to make the electromagnet continuously rotate in a fixed magnet field, converts the energy from electrical to mechanical.

3. The interaction with the magnetic field created by a permanent magnet or another set of coil generates power.

4. The principle of DC motor is to fix the stator, and the rotor moves in the direction of force generated by the interaction.

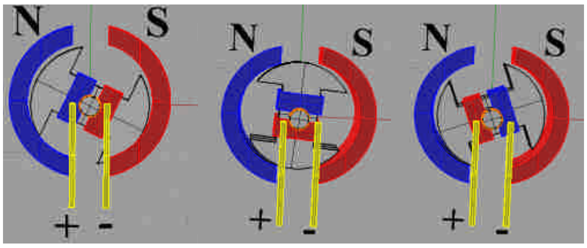


Figure 1 Figure2 Figure 3
Operating Principle Schematic of DC Motor

This is the traditional direct current (D.C) Motor. When the coil is electrified, the magnetic field is created around the rotor, the left of the rotor is pushed away from the left magnet and attract to the right, there by the rotation is generated. (Figure 1)
The rotor continues rotate by the inertia (Figure 2).
When the rotor runs to the horizontal position (Fig. 3) the current converter reverses the direction of the current of the coil, the magnetic field generated by coil also being reversed, resulting in the repetition of this process.

The basic structure of DC Motor includes "Armature", "Field Magnet", "Collecting Ring," and "Brush."
1. Armature: multiple coils wound around a soft core that rotates around the axis.

2. Field Magnet: the strong permanent magnet or the electromagnet that generates magnetic field.
3. Collector Ring: the coil with two semicircular-shaped collector ring connected to both ends turns into a diverter that reverses the direction of current by rotating the coil. Each half-circle rotation (180 degrees) causes one reverse of the current direction.
4. Brush: usually made from carbon. The collecting ring contacts the brush in certain positions in order to be connected to the power supply.

3 Introduction of Brushless Motor

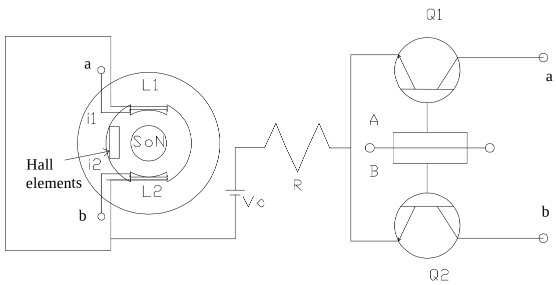


Figure 4 is BLDC Motor with Hall elements

When the rotor magnetic axis coaxial with the Hall element, the Hall element has the shortest distance to the S pole, hence there's the highest magnetic flux density, resulting in at this time the Hall element terminal A retains higher voltage which cause the conduction of transistor Q1 and the current flow i1 in the coil L1. As a result the coil L1 appears to be in excitation state, and according to the right-hand rule that the under side of the coil L1 is the S pole, so the rotor reverses. When the rotor S pole is away from the Hall element, decreasing the magnetic flux density, the Hall voltage is no longer generated in A, B-side and the transistor Q1, Q2 appears to be in OFF state and the rotor is forced by inertia to continue the reverse rotation. When the rotor N pole turns to the Hall element, resulting in the higher voltage in the Hall element terminal B, which causes the conduction of the transistor Q2 and the current flow i2 in the coil L2, the coil L2 appears to be in excitation state, and the rotor is forced by magnetic effect to reverse again, continuously rotating according to this procedure. In Figure 4, because there are two sets of field windings, we call this two-phase Brushless DC servo motor. When higher precision of control is required, the amount of field windings or Hall elements can be increased. Therefore the four-phase, five phase Brushless Motors commonly used in the industry usually entails this BLDC Servo Motor applying the Hall elements.

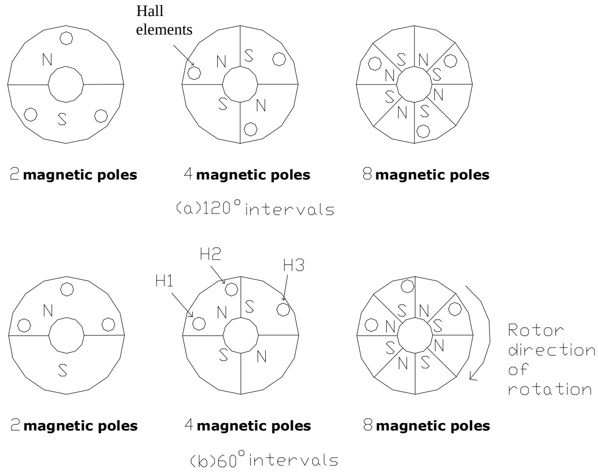


Figure 5 is Hall element adopts the rotor allocation with 120 or 60 degrees interval

Hall element adopts the rotor allocation with 120 or 60 degrees interval, and no matter which of above is adopted, every 60 degrees of rotor rotation there will be a change in any one of the three components. Because within a cycle (with 6 switches) the same signal will not appear again, according to various circumstances, we will be able to configure the logic circuit that generates converting signals. With the collocation of multiple Hall elements we can bring out the effect of relative phase, while the experiment of this dissertation uses three-phase Brushless DC Motor.

1. All Element Theory

In a piece of semiconductor with the thickness d, we let-through the current I, and apply the magnetic field B vertically to the semiconductor piece, therefore from the semiconductor in the direction perpendicular both to the current and the field the Hall voltage VH will be generated. The magnitude of the voltage is in proportion to the intensity of the input current and the magnetic field, and the polarity of the voltage alters with the direction of the magnetic field.

If we make Hall elements along with the relevant circuit into IC, which becomes the Hall IC, is a magnetic - electrical converter which converts physical signals into electrical ones.

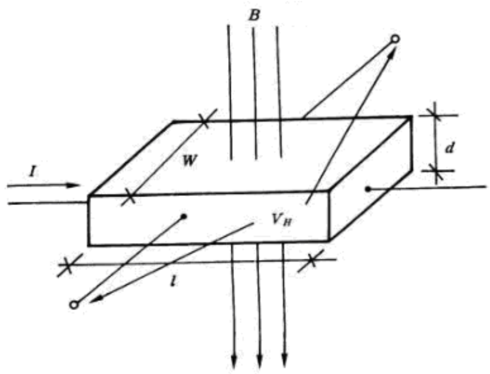


Figure 6 the Hall Element

Hall effect qualifies the following equations:

$$V_H = \frac{K_H}{d} I_H * B\cos\theta + KI_H \text{................................(1)}$$

V_H stands for the Hall voltage, I_H stands for the Hall current, $\frac{K_H}{d}$ is the Hall element electromagnetic coefficient, K is the unbalance factor of the Hall element, and B is the magnetic flux density.

2. PWM Action Principles

Figure 7 This is a simple circuitry，it can by the PWM signal actuation, in the figure, 9V battery power supply for bulb use. If joins the switch close 50ms, in this time, the bulb will obtain the 9V voltage. If in next 50ms, in switch open, the bulb will obtain 0V. If in one second, redundant the such steps 10 times, the light bulb will like connect receive 4.5V (9V one second) the battery to shine equally. Therefore, the PWM signals output work period is 50%, the Frequency Modulation is 10Hz. A lot of load、the inductance and capacitance need more then high 10HZ Frequency Modulation. If increases switch open and the closure time becomes respectively for 5 seconds, Then the work cycle was still 50%, but when the bulb opened, it brightness will increase. For the bulb got only to obtain 4.5V, the work cycle must be smaller than the load the reaction time which switching to the switch. For the bulb got dimmer effective, that must increased modulate frequency size. Above principle is also suitable for other PWM application. Generally, the Frequency Modulation range is 1k Hz to 2k Hz.

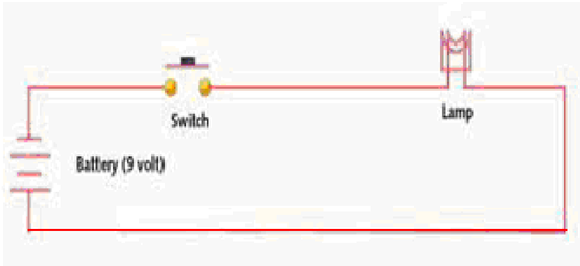


Figure 7 is a simple simulate PWM theorem circuitry.

If figure 8 The PWM circuitry is major function is will input the voltages amplitude transforms into certain width a pulse, in other words, it's will the amplitude of vibration data transforms into pulse width. Generally the switching output circuitry can only output voltage amplitude the fixed signal, for the output resemble the sine wave voltage amplitude the change signal, therefore the voltage amplitude need transform the pulse signal.

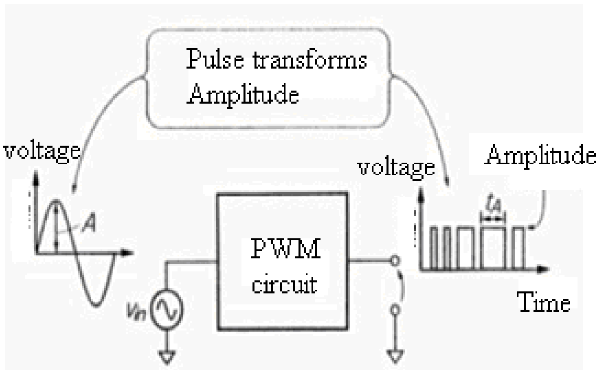


Figure 8 the PWM circuitry is major function

If figure 9. SO high power the circuitry constitute by the PWM circuitry, Gate drive circuitry and Switching output circuitry , the triangular wave compare with instruction to signal, pwm circuitry is major function , they Simultaneously output can drive power MOSFET the control signal, by this control signal control the power circuitry to output voltage.

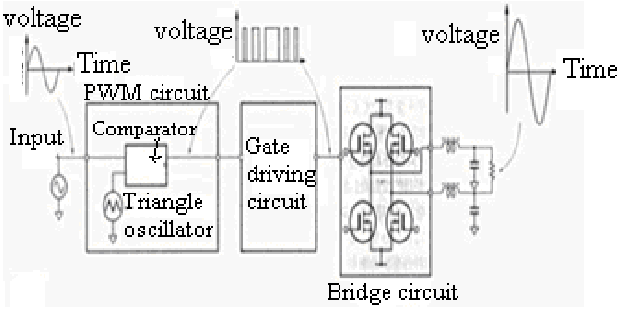


Figure 9 PWM circuitry is important in high power circuitry.

PWM technology [2] is an encoding method for analog signal levels, by using high-resolution counter (frequency modulation) to modulate the duty cycle of square wave, implementing the encoding for an analog signal level. The greatest advantage is that all the signals between the processor and the controlled object are in digital form, hence there's no need for digital-analog conversion process; also the anti-interference ability to the noise is greatly enhanced (only when the noise if strong enough to change the be logical value, it may cause some substantial effect to the digital signal), which is also why the PWM has been widely applied in the signal transmission industries such as telecommunications. [3][4]

5 DC Motor Mathematical Model

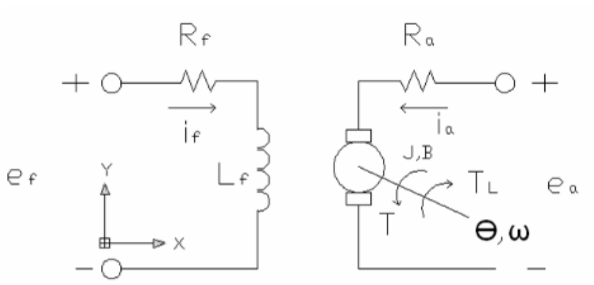


Figure 10.Field-controlled DC Motor System (including the load and damping) of the equivalent circuit [4]

Rf: Field Winding Resistance
Lf: Field Winding Inductance
if: Field Winding Current
ef: Field Winding Input Voltage
Ra: Armature Resistance
ea: Armature Winding Voltage
ia: Armature Current
J: Rotor Inertia
B: Viscous Friction Coefficient
T (t): Motor Torque
Kt: Torque Constant Motor
θ (t): Angular Displacement of the Motor Rotor
ω (t): Angular Velocity of the Motor Rotor

Applying of Kirchhoff Voltage Law in the field winding circuit we get

$$i_f(t)R_f + L_f\frac{di_f(t)}{dt} = ef(t)........................(2)$$

From the torque equation of field-controlled DC Motor we know

$$T(t) = Kt * if(t)..........................(3)$$

Deriving from the mathematical model of the object in rotation movement

$$T(t) - T_l(t) = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt}................(4)$$

To combine expression (3) and expression (4) we get

$$K_t * i_f(t) = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} + T_L(t)..............(5)$$

$$i_f(t) = \frac{J}{K_t}\frac{d^2\theta(t)}{dt^2} + \frac{B}{K_t}\frac{d\theta(t)}{dt} + \frac{T_L(t)}{K_t}...............(6)$$

$$\left(\frac{J}{Kt}\frac{d^2\theta(t)}{dt^2} + \frac{B}{K_t})\frac{d\theta(t)}{dt} + \frac{T_L(t)}{K_t}\right)R_f + L_f\frac{d\left(\frac{J}{K_t}\frac{d^2\theta(t)}{dt^2} + \frac{B}{K_t}\frac{d\theta(t)}{dt} + \frac{T_L(t)}{K_t}\right)}{dt} = e_f(t)......(7)$$

$$\frac{JL_f}{K_t}\frac{d^3\theta(t)}{dt^3} + \frac{(JR_f + BL_f)}{K_t}\frac{d_2\theta(t)}{dt} + L_f\frac{d\frac{T_L(t)}{K_t}}{dt} = e_f(t)..(8)$$

6 BLDC Motor Experiment

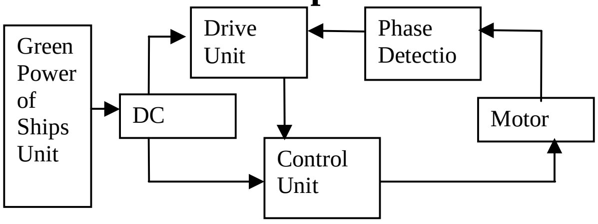


Figure 11.Diagram of BLDC Motor application in Green Power Ship.

To design and draw the construction diagram with CAD and RHINO [5], the basic analysis with CFD [6], milling of each section and keel with CNC, assemble them into patterns, and form the final product with male and female dies. The hull material is mainly produce through FRP procedure. [7][8][9]

The research ship using the FRP system regulation, its flow is as follows: Ship chart Design (fig12 and fig13) → Ship model manufacture → FRP Accumulates the level (fig14) →Mold separation (fig15) → Structure strengthening (fig16 and fig17) → Dynamical equilibrium test (fig18 fig19 fig20). [10][11]

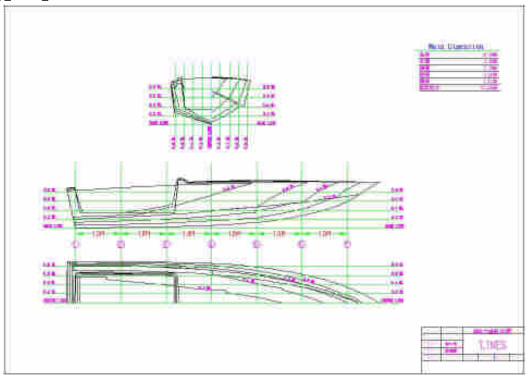


Figure 12 Lines of the ship.

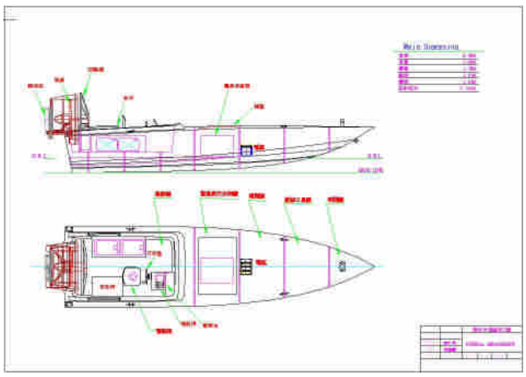


Figure 13 Layout of the ship.

Figure 14 Reinforcement

Figure 15 Finished product from the mold

Figure 16 Longitudinal Frame

Figure 17 Transverse Frame

Figure 18 Front view of the fan

Figure 19 Rear view of the fan

Figure 20 Dynamical equilibrium test.

The under is properties and characteristic a superiority analysis of traditional AC motor and DC brushless motor, BLDC motor proved its superiority.

The word “A” is Traditional AC motor, the word “B” is DC brushless motor[12].

1. The energy consumption and efficiency in makes under the similar conditio.
   A. 150w/35%.
   B. 50w/90%.
2. Noise.
   A. Have obvious AC sound.
   B. Quiet.
3. Volume/Weight.
   A. The traditional AC motor volume is big, it is heavier approximately 1/3 ~ 1/2 than DC motor.
   B. The DC brushless motor volume is small, the weight is light, the weight is 2/3 ~ 1/2 to traditional AC motor.
4. Cost comparison.
   A. The traditional AC motor, if the same power output to compare, it's about the same material cost as BLDC motor.
   If needs the driver coordinates in produce market, then its driver cost definitely will be more complex than BLDC Driver, the cost will be higher.
   B. If the motor material cost will to become commercial quantity produces, it is about the same material cost as the traditional AC motor. The BLDC is programmable of driver system of Mechatronics, than the driver material cost will be cheaper than the traditional motor.
5. Compare flow Processing.
   A. The material cost is more expensive about 1/3 than BLDC motor, when processing is time-consuming.
   B. The material cost is cheaper about 1/3 than traditional AC motor, the processing is simple.
6. Torsion.
   A. When uses in thermolysis or range hood , its torsion is small, it is no power push bigger vane or bigger angle vane, because the traditional AC motor with case resonate, so it creates noise.
   B. It has high torsion, so it is match up big vane and bigger angle vane. It has more air volume and air pressure in slow rotational speed.
7. Rotational speed.
   A. Voltage frequency (50/60HZ) is limit of Rotational speed, it is can't modulation.If adjust speed need use the converter, than cost is more expensive than motor.
   B. BLDC motor can stepless transmission, it is use simple, also potential multi-purpose and Fuzzy function a circuit, it can automatic adjust rotational speed because environmental temperature is change.
8. Temperature.
   A. Temperature has rise about 95°
   B. Because the efficiency is high, the power input above 85% can transforms work by kinetic energy , so transforms only rise in 40℃ －45℃.
9. Cost and Pollution.

A. The procreation is long, complex and has environmental pollution. Materials cost is expensive because the volume is big.
B. The volume is small, materials cost is low about 1/3, procreation is shorter and not have environmental pollution, so it is not need varnish process.

10. Application scope.
A. It is has spatial limitation, elasticity is small and torsion is small because volume is big, also the mostly applicable scope is only single purpose.
B. The volume is small, so it is has not restrained space, torsion is bigger and applicable scope is bigger, it is save developmental cost because it is versatile.

11. Life span.
A. It is easy produce a short circuit and burned questions etc because it is high temperature.
B. The life span is long because it is low temperature.

7 Experiment and analysis

We take NACA68014(Figure 21) as the reference modle, then changes its attack angle by 5 degrees to 40 degrees, we use the CFD (Computational Fluid Dynamics) to 2D analysis of a vane section[13][14].

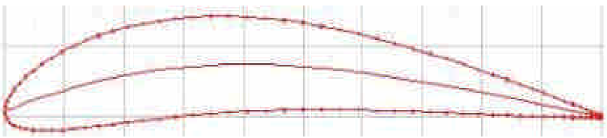


Figure 21 NACA 68014

Theoretical calculation:
In the computation, the vane and pitch are fixed, the vanes changes from two pieces to six piece, the vane periphery speed ratio (λ) counts two to six pieces to a completely functions of curves.
All of parameters dimensionless were for convenient to compare.
The definitions are as follows:

Vane periphery speed ratio, $\lambda = \omega R / U_{\infty}$ ....(9)

Power coefficient, $C_P = \dfrac{Power}{\frac{1}{2}\rho U_{\infty}^2 \pi R^2}$ ....(10)

Torque coefficient, $C_T = \dfrac{Torque}{\frac{1}{2}\rho U_{\infty}^2 \pi R^3}$ ....(11)

Resistance coefficient, $C_D = \dfrac{Drag}{\frac{1}{2}\rho U_{\infty}^2 \pi R^2}$ ....(12)

R is vane radius .
ω is vane rotational speed.
ρ is air density.
U∞ is free-stream speed.
Torque is the wind affect the vane produces torque.
Power is the wind affect the vane produces power, it is **ω×Torque.**
Drag is the wind affect the vane produces axial resistance.

Vane power analysis:
The figure 22 is tested the vane tangent directions to contours of velocity magnitude drawing.

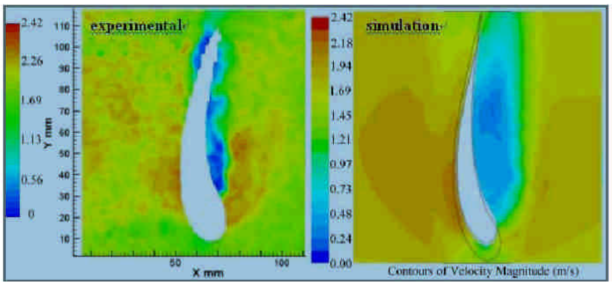


Figure 22 is the vane tangent directions to contours of velocity magnitude drawing.

The figure 23 and 24 show that the vane directions of tangent streamline and vector diagram,in the figure, we can looking the vane end parts produce slowly vortex, it means flow speed is slower than start vane. Furthermore, the vane tangent direction sustain more wind speed, the vane surface static pressure is smaller. When the speed is smaller, the surface static pressure is bigger.[15][16]

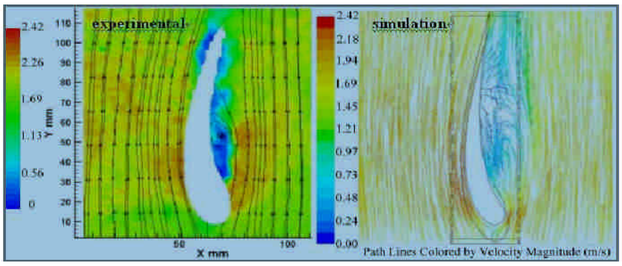


Figure 23 is the vane tangent directions to path lines colored by velocity magnitude drawing.

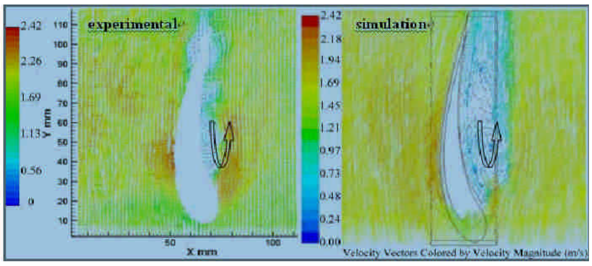


Figure 24 is the vane tangent directions to veloeity vectors colored by velocity magnitude drawing.

Figure 25 to 32 is the wind affect the vane produces flow field velocity magnitude drawing from angle of attack five degree to forty degree.

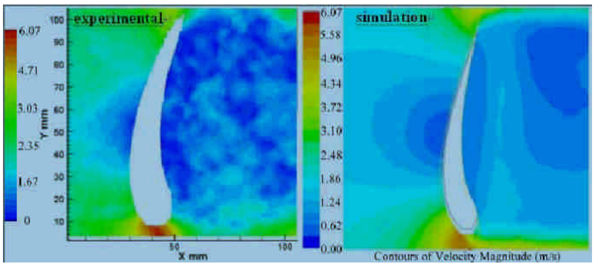


Figure 25 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 5°)

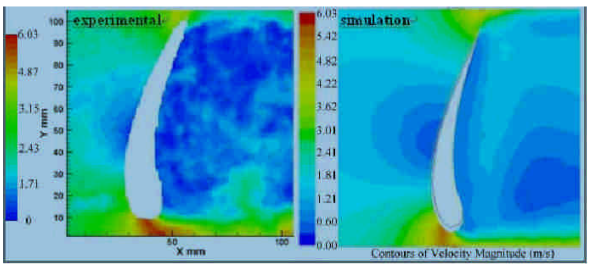


Figure 26 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 10°)

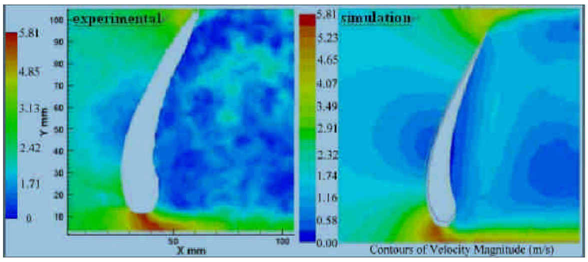


Figure 27 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 15°)

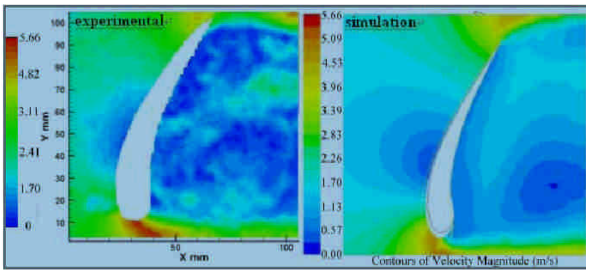


Figure 28 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 20°)

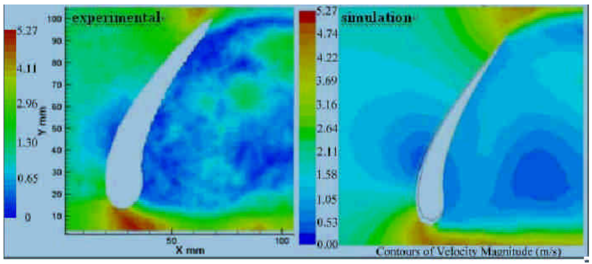


Figure 29 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ =2 5°)

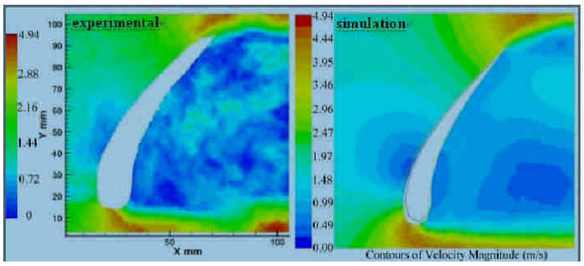


Figure 30 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 30°)

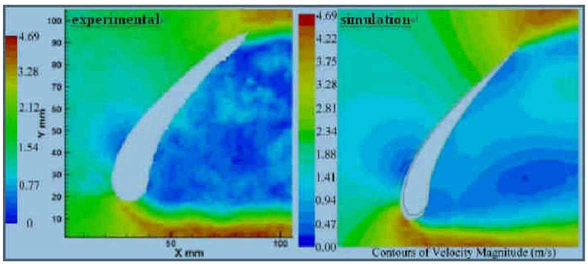


Figure 31 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 35°)

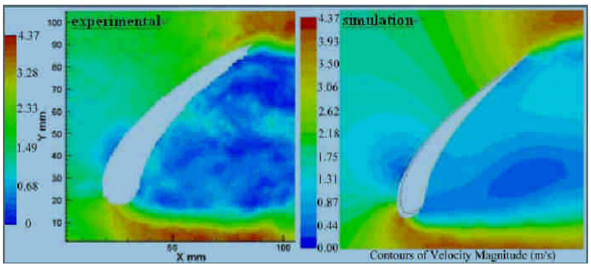
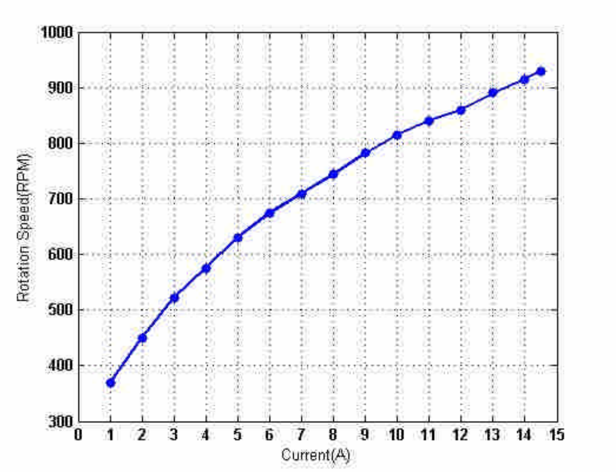


Figure 32 is the wind affect the vane produces contours velocity magnitude drawing (Angle of Attack ψ = 40°)

Table 1 was recorded experiment BLDC motor rotational speed, it use tachometer and circuit tester.

Table 1.Diagram of BLDC Motor Rotation Speed and Current



8 Conclusion

The CFD analysis in viscous flow theory is important, since its can show flow field characteristic, its can add designer understand and contorl for vane flow field, it is important in vane technology develop.

The wind affect the vane produces flow field velocity magnitude drawing from angle of attack five degree to forty degree, we observe the vane when the angle of attack is very small,that liberated aerodynamical resistance the edge of start parts,in this time the edge of start vane affected pressure bigger than the edge of end vane, the edge of start vane affected ot push the edge of end vane to become angle of attack,when the vane angle of attack starts the biggest angle, then the vane change flow field status to decrease the vane affecte aerodynamical resistance and become to divide equally flow field.

BLDC Motor technology features High-performance, power saving, low noise, high speed, low loss etc. is now replacing the conventional AC electric motors, and in the water crafts such as green power ships (in the case of this experiment is wind driven vessel), the importance of the energy saving and high output performance has become neglected. In the experiment, the data has achieved the high speed out along with low power consumption, and also the proportional linear growth of its power and speed, which represents the stable output speed even in the circumstance of low current. This kind of motors has become worthwhile to apply PWM to collocate with fuzzy control of ships. This will achieve the optimal control above the speed of the wind and the ship as well as the energy monitoring system, which is the goal of future green power ship research.

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