The Research on Driving force and Elements of Main & Side Hulls of Amphibious Maintenance Trimarans in Wind Farm

Yunping Xie, Yunsiya Zhou, Song yu, Weigang Xie, Liangdong Qi

***Abstract*— This paper are based on requirements of maintenance on intertidal wind farm in China, Through demonstration, comparison and analysis, it can be determined that the propulsion system on water adopts regular propeller, driving mode on land adopts wheeled mode. For power transmission, mechanical transmission is used while sailing on water and hydraulic transmission is used while driving on land, therefore an affordable, feasible as well as reasonable single-motor propelled system can be determined. Numerical simulation is used to analyze and calculate hydrostatic resistance, pitch and heaving of several amphibious maintenance trimarans which adapt different main, side hull arrangements in regular wave and determine relative position and scheme of main, side hull of amphibious maintenance trimaran. The research results in this paper will provide references for the design and research of amphibious maintenance ship for offshore intertidal wind farms.**

***Index Terms*— Maintenance in wind farm; Amphibious; Trimaran; Driving mode; Main side elements**

I. INTRODUCTION

Wind energy can never be used up, especially as a kind of clean energy. By the end of 2016, the installed capacity reached 14382MW in the world, China reached 1630MW (the intertidal occupied about 60%)[1] . According to the newest report, offshore wind farm projects in progress in China reached 2308MW in 2016, among them intertidal projects reached around 1500MW[2-3] , and mainly installed along the yellow sea in the middle east of China with excellent wind source.

The intertidal maintenance traffic tools need to meet the dual usage and performance requirement on land as well as on sea. At present most intertidal maintenance traffic tools are conventional mono-hulled ships and agrimotors which influenced hugely by tide; there are also few wind farms adopted amphibious cars(ships), even hovercrafts, however they are difficult to meet seakeeping and maneuverability requirements in wind farms.

Therefore, this paper based on the maintenance requirements of offshore intertidal wind farm in China to launch a survey into amphibious driving method and main side hull elements of amphibious maintenance trimaran. It will pose some practical value in engineering area.

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II. DRIVING METHOD OF AMPHIBIOUS SHIP

A. Driving method on sea

Propeller impetus and water jet propulsion are the two main propulsion type on water for amphibious ship. Propeller propulsion make amphibious ship move forward by wheeling propeller driven by transmission shaft, and achieves diversion and sternway by rudder or changing direction of rotation of propeller. This propulsion method on water is relatively reliable, but the propulsion control equipment is complex, paddle failures happen easily when meet obstacles. So, some amphibious ships adopt propeller which can be overturned and fixed, or arrange propeller at the tail tunnel of car.

The water jet propulsion device uses an axial pump to generate thrust by the reaction of discharging water to drive amphibious vessels. Since the propeller is installed inside of the hull, damage of propeller can be avoided when amphibious ship driving on land, landing, launching, and driving on shallow. In addition, water jet (with reversing device) can achieve diversion and sternway without changing turning directions of impellers to ensure that the amphibious ship obtains good maneuverability.

The speed of maintenance ship is always under 20 knot, the efficiency of water jet propulsion is lower than propeller in this situation. In addition, since sediment concentration is comparatively higher in intertidal area, it is easy to pose abrasion on water jet propulsion and lower its efficiency and the price of jet propulsion is higher than propeller propulsion. So it is reasonable to adopt propeller propulsion for amphibious maintenance ship in wind farm.

B. Driving method on land

According to different driving method on land, amphibious ship(car) can be normally divided into crawler-type amphibious ship(car) and wheel-type amphibious ship(car). Crawler-type amphibious ship(car) drive on land with tracks, it’s rideability is superior to wheel-type amphibious ship(car), but crawler is inconvenient to retract for it’s huge self weight. On the other hand, for economical aspect, high price of tracks will increase cost of installation significantly.

Wheel-type amphibious ship (car) drive on land with tire, the advantages of wheel are: relatively light weight, lower cost and it is easier to achieve arrangement, contraction and release of tires.

Amphibious maintenance ship in wind farm requires comparatively high speed no matter on land or on sea, that means, when it sailing on sea, walking device used on land should be retracted to reduce resistance; when walking on land, self weight should be low to guarantee rapidity and maneuverability. High self-weight of crawler-type amphibious ship makes it inconvenient to retract, and the cost of crawler-type amphibious ship is higher. In contrast, wheel-type amphibious ship is lighter, cheaper and achieves contraction and release of tires more easily. It can meet requirements of usage and performance in offshore intertidal wind farm better.

III. POWER MODES OF AMPHIBIOUS SHIP

A. *Power transmission type*

Power transmission normally include mechanical transmission, electric transmission and hydraulic transmission[6]. For amphibious maintenance trimaran in wind farm, it is feasible to arrange main engine, shaft and propeller at the main hull and arrange walking device at side hull. Although the structure of mechanical transmission is comparatively simple, the arrangement of shafting is restricted. Electric transmission need support of power station and electrical distribution system which lead to the increase of weight and cost, and dynamo can be damaged easily in harsh ocean environment. It is also difficult for electrical transmission to achieve rigid fixation of tire position.

Hydraulic transmission is easier to control, and works safely and reliably. This method can transfer mechanical energy which come from main engine in main hull into hydraulic energy and deliver the energy to hydraulic motor in side hull to drive and control amphibious ship when traveling on land. Hydraulic energy can also be applied to oil cylinder which control the position of tire device when traveling on water or land.

In conclusion, it is more reasonable to adopt hydraulic transmission on land, and adopt mechanical transmission on water.

B. *Power-driven System*

Amphibious ship usually adopt two kind of power-driven system. One is dual-energy and dual-drive (Figure I), that means outboard engine is adopted to achieve propulsion on water, while on land power-driven system is similar to car's. Two subsystems of this power-driven system are comparatively independent, the arrangement of devices is comparatively scattered.

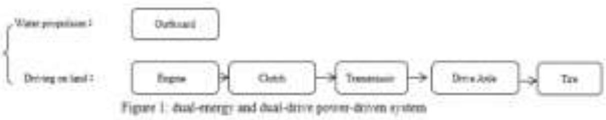


Fig. I Dual energy and dual drive power-driven system

Another one is single-motor and dual-drive power-driven system (Figure II), that means transfer case is set to switch power-driven modes between water mode and land mode. The structure of transfer case in this system is comparatively complex.

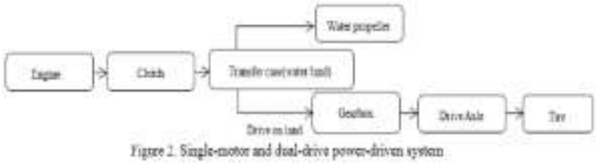


Fig. II Single motor and dual-drive power-driven system

Taking usage, arrangement and other elements into consideration, amphibious maintenance trimaran in wind farm adopt a suit of single-motor and dual-drive system (Figure III), that means diesel provides power, on one hand, it drives propeller through tail shaft activated by flywheel end to achieve sailing on water; on the other hand, it drives hydraulic pump through free end and hydraulic energy drives hydraulic motor to achieve moving on land. This system saves space, contains less equipment, is easy to control and transfers power efficiently with comparatively low cost.

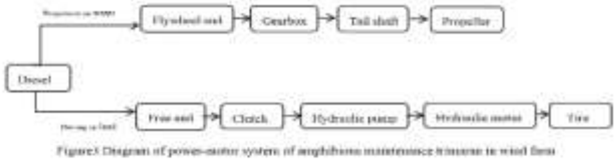


Fig.III Diagram of power-motor system of amphibious maintenance trimaran in wind farm

IV. ELEMENTS ANALYSIS OF MAIN/SIDE HULL

A. *Main elements of main hull*

According to the features of usage and performance of maintenance ship in wind farm, amphibious maintenance trimaran in wind farm can be regarded as on the basis of high speed single-hull ship, other two side hulls are added to the right and left side of main hull separately. So it's main elements can be analyzed and confirmed by referring to high speed single-hull ship and maintenance trimaran in wind farm.

1) *Length of main hull*

Length of trimaran is mainly considered from resistance performance and arrangement. For high speed single-hull ship, the residual resistance coefficient[8] (Figure IV) is related to Froude number and length coefficient of displacement, and it is relatively suitable when Froude number is around 0.8. the required speed is 15kn for this amphibious ship, then the waterline length should be less than 9.5m.

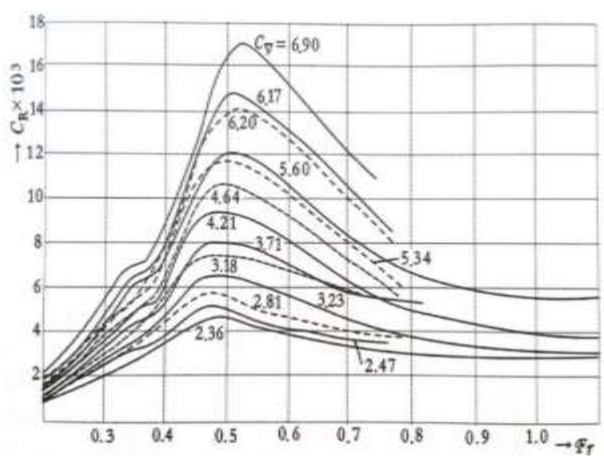


Fig. IV Relationship between residual resistance coefficient Cr and Fr

Arrangement of main engine room and requirement of main deck area will be mainly considered in arrangement of amphibious trimaran. Although main engine room area and main deck area will relatively ample when length is long, handing performance on land will be influenced at the same time. On the premise of warranting arrangement of engine room, length should be reduced as much as possible, so waterline length can be determined preliminarily as 9m with comprehensive consideration.

2) the breadth of main hull

The breadth of main hull is determined mainly considering the need of transverse arrangement of engine room and suitable length-breadth radio. The breadth of the ship's engine room shall be ensured for the layout of the main engine and proper maintenance passages on both sides, that is, no less than the breadth of the main engine 711mm, plus 2×500 mm of maintenance passages on both sides. In addition, combined with the ratio of length to the breadth of main hull of the existing maintenance trimarans. (usually in the range of 5.00~5.36) [9], breadth range from 1.81 to 1.94. Considering the benefit to the rapidity, the main breadth is determined as 1.8m.

3) Draft and depth of main body

In order to improve the operation rate on water as much as possible, according to the tide situation of intertidal zone, the draft of this ship should be controlled within 0.8m, and the propeller should be designed under this situation.

The depth of main hull usually considered from the main cabin's vertical layout and freeboard. According to the relevant laws and regulations [10], vertical distance from the highest deck of the high speed deck boat to the waterline shall be no less than 1.63m, and the vertical distance from the connecting bridge to the full-load waterline shall be no less than 0.066Lm that is 0.59m. For the cabin vertical layout, if the propeller shaft center line height is 0.40m, combined with the gear box input and output shaft height difference 0.1m and height above diesel engine crankshaft 0.65m, and consider the space of 0.50m, the depth is around 1.65m.

4) Form coefficient of main hull

When the length, breadth and draft are determined, the block coefficient directly determines the size of the displacement, so it has a certain influence on the resistance. According to the ship, Froude number is 0.82, the prismatic coefficient is calculated as 0.656 according to formula $Cp=0.6757Fr^{0.14744}$. Referring to statistics of trimaran block coefficient value of 0.41~0.46[9], when the block coefficient of main hull is 0.41, it can have a good match with prismatic coefficient, and the displacement is relatively small, which is 5.3t.

B. Elements of side hull

In determining the elements of the side hull, the amphibious ship's performance on water and the influence of the performance on shore should be taken into account. From the point of view of the performance on water, the main role of two side hull is to improve the stability and improve the seakeeping; from the point of view of the driving performance on land, since the layout of tyre and its releasing device should be installed on stem and stern, the scale and layout has great influence on the driving performance of amphibious ship on land.

1) Length of side hull

On water, the length of the side hull has a certain relationship with the total deck area of trimaran. According to the statistics data of the operation and maintenance trimaran in wind farm, the ratio of the length of side hull to the length of main hull is usually 0.38~0.54[9].

On land, the length of the side hull directly determines the front and back wheelbase of the amphibious boat, thus affecting the stability on the intertidal beach and the flexibility of the operation. According to reference [11], the ratio of wheelbase to wheel length of car is generally 0.52~0.66.

Considering the trimaran performance on water and performance on land, the ratio of length of side hull to main hull is 0.54, therefore the length of side hull is 4.90m.

2) Breadth of side hull

To determine the breadth of side hull, in addition to considering the stability of the whole ship, it is also necessary to minimize the influence on the total resistance of side hulls. Taking reference of ratio of side hull breadth to main hull breadth of operation and maintenance trimaran which is around 0.35 and the ratio of length to breadth of side hull which is 7.38~8.00[9], therefore the side hull breadth is set to 0.63m, and the ratio of length to breadth is set to 7.78.

3) Draft and depth of side hull

The ratio of displacement of the side hull to the main hull is an important factor affecting the performance of trimaran. Usually, the displacement of high-speed trimaran's side hull does not exceed 10% of the main hull's [12], namely 0.53t. According to the equation of buoyancy, if the block coefficient is 0.41, the draft of side hull should be about 0.42m.

The moulded depth of side hull should coordinate with the main deck, that means the freeboard of side hull need be matched with the freeboard of main hull, in other words, depth of side hull can be considered to be not less than the draft of main hull added with upper freeboard draught, namely 1.27m, therefore real depth is set to 1.3m.

C. Relative positional parameters of main and side hull

For the amphibious trimaran, in addition of the self-element of the main hull and the side hull, the relative positional parameters of the main and side hull, which lead more influences to the navigation on water and the performance of driving on land, are more important. As shown in Figure V.

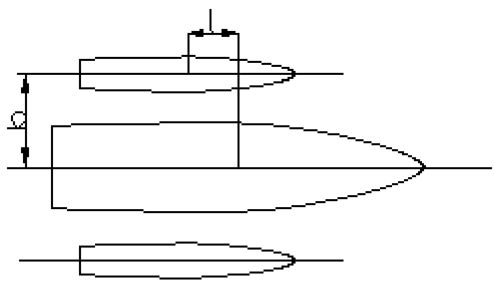


Fig. V Sketch map of relative positional parameters of trimaran's main and side body

At the point of sailing performance of trimaran, researches show that [13-15], what be beneficial to reduce the resistance of the side hull's vertical layout is: when in the medium and low speed, side hull should be arranged slightly after the center of the main hull; when in high speed, side hull should be arranged in the rear part of the main hull (almost in the same level of rear-end). Referring to the existing wind power operation and maintenance trimaran in wind farm, the ratio of the difference between length center of the main hull and the length center of the side hull to the length of the main hull Lm is 23.53%~29.62% [9]. For the transverse pitch of side hull, the range of b should be moderate. If b is too small then the interference among plates are mostly disadvantageous; if b is too large, then the requirement for the strength of the connecting bridge of the trimaran is strict, and the metacentric height is too bid, which is not conducive to the roll performance of the amphibious trimaran on water. Referring to the existing operation and maintenance trimaran in wind farm, the ratio of transverse distance b to the breadth Bm of main and side hull is 95.24%~105.56%[9].

From the aspect of amphibious ship's driving performance on land, vertical layout of side hull determine the load distribution of amphibious ships on front and rear axle, and have a certain extent affect to the amphibious

ship's power performance, trafficability, braking performance and steering stability [16]. For amphibious ships, in order to ensure that the wheel load distribution is relatively uniform, the ideal position of the side hull's vertical layout is the longitudinal center of gravity of amphibious ship near the center of the wheelbase, that means the longitudinal position of the side hull should be closer to the rear (the longitudinal position of the center of gravity of the amphibious trimaran is about 17% after midship of main hull). The horizontal layout of side hull determines wheelbase of amphibious ship. With wheelbase increasing, the lateral stability of the amphibious ship on land can be improved, but the total breadth and weight of amphibious ships also increases, and it also influences the minimum turning radius.

To sum up, the layout of the lateral hull of the amphibious trimaran is preliminarily determined at range of: *l/Lm*=11.5%~23%, *b/Bm*=89%~111%.

V. Optimization of Main Side Body Layout

In order to optimize the layout of amphibious maintenance trimaran in wind farm, the method of CFD [17] is adapted to analyze resistance, pitch and heave of each layout.

A. Calculating ship model parameters and mesh model

In order to study the influence of the difference of layout on resistance, a ship model, which scale ratio is 1:10, is used to do calculations, the main parameters of main hull and side hull are as shown in Table I, The mesh model of amphibious ship model which is generated by the hexahedral unstructured grid generator of CFD software, is shown in figure VI.

Table I Main parameters of main body and side body

Parameter	Main body	Side body
Waterline Length Lwl/m	0.900	0.490
Waterline Width B_{wl}/m	0.180	0.063
Displacement Δ /kg	5.300	0.530
Designed Draft d /m	0.080	0.042
Block Coefficient C_b	0.410	0.410

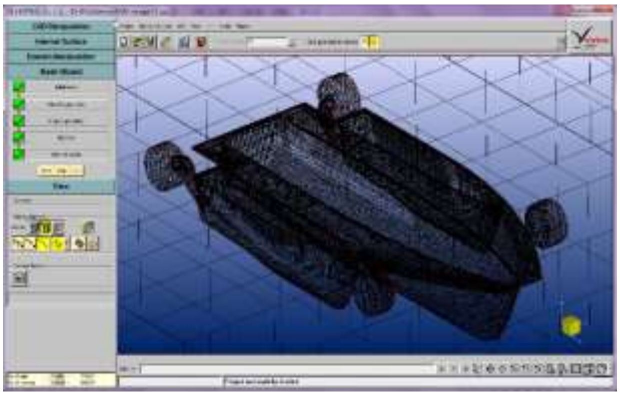


Fig VI Mesh model of amphibious ship

B. Different main body layout scheme

According to the range of location parameter of the main and side hull as determined above, the scheme shown in Table II is set up.

Table 2 Different main body layout scheme of trimaran

Side body layout scheme	Longitudinal distance l /m	Transverse distance b /m	l/L_m	b/B_m
Scheme 1	0.205	0.160	23.00%	88.89%
Scheme 2	0.205	0.180	23.00%	100.00%
Scheme 3	0.205	0.200	23.00%	111.11%
Scheme 4	0.155	0.160	17.25%	88.89%
Scheme 5	0.155	0.180	17.25%	100.00%
Scheme 6	0.155	0.200	17.25%	111.11%
Scheme 7	0.104	0.160	11.50%	88.89%
Scheme 8	0.104	0.180	11.50%	100.00%
Scheme 9	0.104	0.200	11.50%	111.11%

C. Numerical simulation analysis of hydrostatic resistance

The numerical simulation method of resistance performance based on FINE/Marine is used to study the simulation of hydrostatic resistance in the range of Froude number Fr=0.1~1.1 for the model of amphibious trimarans with 9 different side configurations

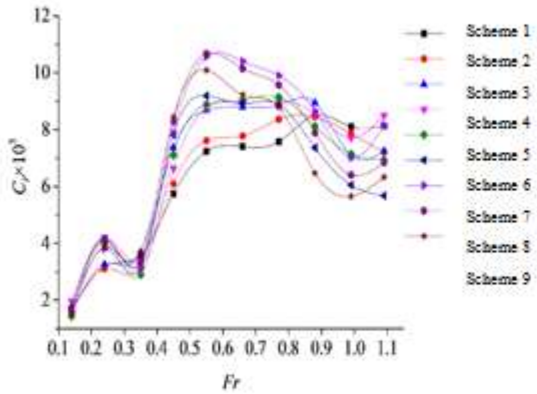


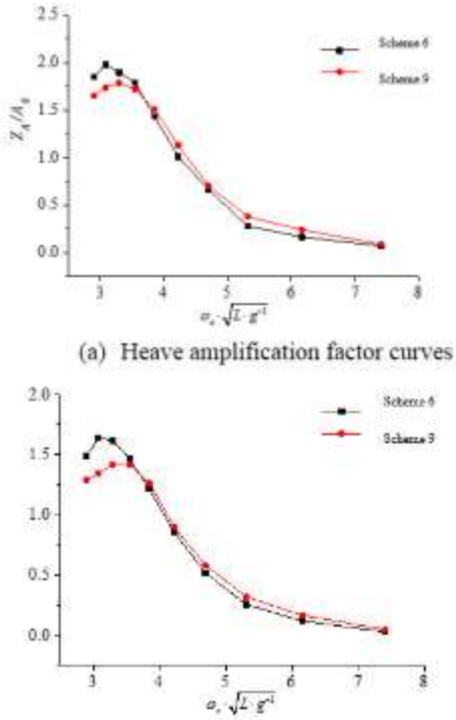
Fig VII Residual resistance coefficient of each scheme

We can see from Figure VII, the residual resistance coefficient increase with increase of Froude number, showed the trend of increasing firstly and then decreasing, and the scheme 6 and 9 in the Froude number of 0.82, show better performance of resistance.

D. Numerical simulation analysis of seakeeping

According to the procedures of ship seakeeping test [18], taking regular wave height H as 1/50 of amphibious trimaran's length, the wavelength λ as 1.0~3.25 times of length Lm, wave period $T=0.8\lambda^{0.5}$, the natural frequency $\omega=2\pi/T$, encounter frequency $\omega=\omega_e=\omega+\omega^2\cdot V/g$ (V is speed). Simulation calculation and comparison are conducted to analyze seakeeping performance for scheme 6 and scheme 9.

In order to measure the extent of the motion response of a trimaran in regular waves, the dimensionless parameter of the magnification factor (RAO) is introduced as the ordinate of the motion response curve. The heave amplitude and pitching amplitude were conducted to get heave amplification factor Z_A/A_0, pitch amplification factor θ_A/α_0, where Z_A is the heave amplitude, A_0 is regular wave amplitude, θ_A is pitch amplitude, α_0 regular wave surface wave tilting, $\alpha_0=2\pi A_0/\lambda$. After dimensionless treatment, the heave amplification factor curves of scheme 6 and scheme 9 are shown in Figure 5 (a), and the pitching amplification factor curves are shown in Figure 8 (b).



(a) Heave amplification factor curves

(b) pitching amplification factor curves

Fig. VIII curve of seakeeping performance

As we can be seen from figure VIII, the heaving and pitching amplification factors of the two schemes of the trimaran are increased firstly, then decreased, and gradually leveled down with the increase of frequency. Scheme 5 is better than the scheme 9 on seakeeping performance, but the gap between two alternatives is very little and have the trend to approach the same point.

At the point of rapidity and seakeeping, two main performance index on, hydrostatic resistance and seakeeping performance of scheme 6 (l/Lm=17.25%, b/Bm=111.11%) is superior, and the side hull layout of scheme 6 can better meet the requirements of amphibious ship like smooth running, flexible handing, uniform wheel load distribution when driving on land, and ensure the tire device layout and retractable safety at the same time (see Figure IX).

(a) on land

(b) on water

Fig. IX 3D visualization

VI. Conclusion

According to the requirements of operation and performance of amphibious maintenance trimaran in intertidal zone, through the analysis of amphibious driving mode, the power transmission and drive system, driving method can be determined as regular propeller propulsion on water and tyre-mode driving on land, power transmission method can be determined as mechanical transmission on water and hydraulic transmission on land, and then an economic, feasible and reasonable single power driving system can be determined. Using CFD numerical simulation method, with the selected main elements of main and side hull, to analyze and calculate pitch and heave in stillwater and regular wave of different side and main arrangement scheme for amphibious maintenance trimaran, the final scheme take high speed navigation on water as principle driving method and supplemented by driving on intertidal zone. The following conclusions are obtained in this paper:

1) The amphibious trimaran in the intertidal zone is driven by a single power system, and it is more economical and feasible to use mechanical propeller transmission mode on water and tyre hydraulic transmission mode on land.

2) The layout scheme of main and side hull (l/Lm=17.25%, b/Bm=111.11%) is selected, and its hydrostatic resistance, pitching and heaving performance are better.

The power-driving and driving modes of the amphibious trimaran proposed in this paper can be used as a reference for the design and development of operation and maintenance ships in intertidal wind farm. Please write it out what is wrong in this article.

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