Third International Symposium on Marine Propulsors
smp'13, Launceston, Tasmania, Australia, May 2013

An Integrative Design Method of Propeller and PBCF(Propeller Boss Cap Fins) *

CAI Hao-peng[1], MA Cheng[1], CHEN Ke[1], QIAN Zheng-fang[1], YANG Chen-jun[2]

[1]Institute of Naval Academy of Armament, Beijing 100161, China
[2]State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

ABSTRACT

Mostly, PBCF design depends on the optimal selection of model test results, and the interaction between PBCF and propeller is not considered sufficiently. In this paper, PBCF and propeller are considered as a whole system and the design of them is an integrative process, in which the concept of uploading in blade root is merged. The load distribution of blade becomes well-proportioned due to the uploading in blade root, and it is advantageous to the depression of vibratory force and blade tip vortex. The blade root area has larger thickness and strength, and it is difficult to be vibrated, therefore, uploading is beneficial to noise reducing. The disadvantage of uploading in blade root is the generation of hub vortex behind boss cap, but the hub vortex can disappear because of energy saving hydrodynamic mechanism of PBCF. Therefore, the integrative design method introduced in this paper can provide higher efficiency propellers for the same design conditions.

In this paper, an integrative propeller and PBCF design method including theory design and numerical optimization design is finally presented, which is based on potential flow theory, CFD tools, improved particle swarm optimization algorithm, and model tests research. Model test results show that the propeller and PBCF designed in this research has higher efficiency, and the design method is effective, reliable and practical.

Keywords

PBCF; integrative design; uploading in blade root

1 INTRODUCTION

PBCF is an effective energy saving device, which can recover the energy loss of propeller hub vortex in the propeller down stream flow and eliminate the low-pressure area behind boss cap. PBCF consists of some small planar fins fitted on propeller boss cap, and rotates together with the propeller. Since PBCF has been invited as a novel energy saving device in 1987, the effectiveness of it is confirmed by both model and full scale tests (OuchiK 1988,1989, TakeoN 2010). Statistical analysis of lots of actual vessels voyage data indicates that 3%-7% efficiency gains can be achieved. Figure 1 shows a PBCF installed on a ship.

Figure 1 PBCF installed on a ship

The hydrodynamic mechanism of PBCF can be summed up as follows: ① propeller thrust increases by the disappearance of low-pressure area behind boss cap due to breaking up the hub vortex; ②total propeller torque decreases because the force acting on the fin reacts as inverse torque by the rectification of down stream flow from the propeller blade trailing edge.

Mostly, PBCF design work depends on the optimal selection of model test results, and the interaction between PBCF and propeller is not taken into account sufficiently. In this paper, PBCF and propeller are considered as a whole system and the design work of them is an integrative process. In order to achieve more efficiency gains, based on the hydrodynamic mechanism of PBCF, the concept of uploading in the blade root is presented in the design method. An integrative design process of propeller with PBCF for a cargo vessel is introduced in the paper, and model test results show that the propeller with PBCF designed by the integrative method has higher efficiency under design condition.

2 TRADITIONAL DESIGN METHOD OF PBCF

2.1 Optimal selection of model test results

Combining empirical design with model test validation is a widely used PBCF design method in engineering applications. Designers usually choose a series of geometric parameters of PBCF empirically, and select the optimal one as the design output according to model test results of PBCF. This method is simple and practical, also the model test result is reliable, and so designers can normally get the appropriate design scheme through it. However, this method can hardly find the most efficient PBCF, because designers have limited samples to make their choices, moreover the samples depend on one's experience largely. In addition, optimal selection based on model test results is unable to avoid the disadvantage of model test's own, such as the scale effect.

2.2 Theory design method

In the 1990s, the theory design method of PBCF has appeared (HU 1991, LI 2012), based on the potential flow theory including lifting line and lifting surface model. In this method, PBCF is regarded as a turbine or tandem installing behind the propeller, and the induced velocity of propeller is taken into account when designing. However, propeller and PBCF are seen as two separate parts in this method, for the propeller geometry is fixed during the design of PBCF, so the effect of PBCF upon propeller is not considered. The theory design method of PBCF is not used widely in the engineering application.

3 AN INTEGRATIVE DESIGN METHOD OF PROPELLER AND PBCF

As for the energy saving mechanism of PBCF, it makes sense that the stronger the hub vortex broken up by PBCF is, the more energy will be recovered. Therefore, if the load in inner radius of propeller is increased, the efficiency gains of PBCF will rise accordingly, and the energy saving potential of PBCF can be developed sufficiently. Besides, uploading in the blade root brings other advantages. For example, the blade load moves to the inner radius properly, and the consequently modified well-proportioned radial load distribution is advantageous to the depression of vibratory force and blade tip vortex; the blade root area has larger thickness and strength, and it is difficult to be vibrated, therefore, uploading is beneficial to noise reducing.

In this paper, the potential flow theory including lifting line and lifting surface theory is used as a preliminary design method. Then, viscous flow CFD tools simulate and analyze the flow field around propeller and PBCF. And the improved PSO (particle swarm optimization) algorithm (CAI 2009) is selected to adjust both propeller and PBCF slightly. After that, model tests results of design output serve as a validation and modification method for the integrative design work. Repeated iterations of each design part finally construct the design method for propeller with PBCF. The integrative design procedure can be expressed by the flow chart shown in Figure 2.

4 DESIGN SCHEME AND MODEL TEST VALIDATION

4.1 Design scheme

Two propeller with PBCF schemes named as A and B are designed for a cargo vessel. PBCF of scheme A is designed to match the original propeller of the cargo vessel, and PBCF and propeller of scheme B are newly designed by the integrative method presented in this paper. Figure 3 shows the radial circulation distribution of both scheme A propeller and B propeller. It can be seen from figure 3 that the propeller of scheme B has larger circulation in inner radius than that of scheme A propeller.

Table 1 shows parameter comparison between scheme A and B. The main difference of scheme A and B is the propeller pitch ratio in inner radius and the installed angle of PBCF. For the convenience of comparison in this paper, the other parameters of propeller such as diameter, blade number, area ratio, skew, rake, thick distribution, blade section are set to the same value.

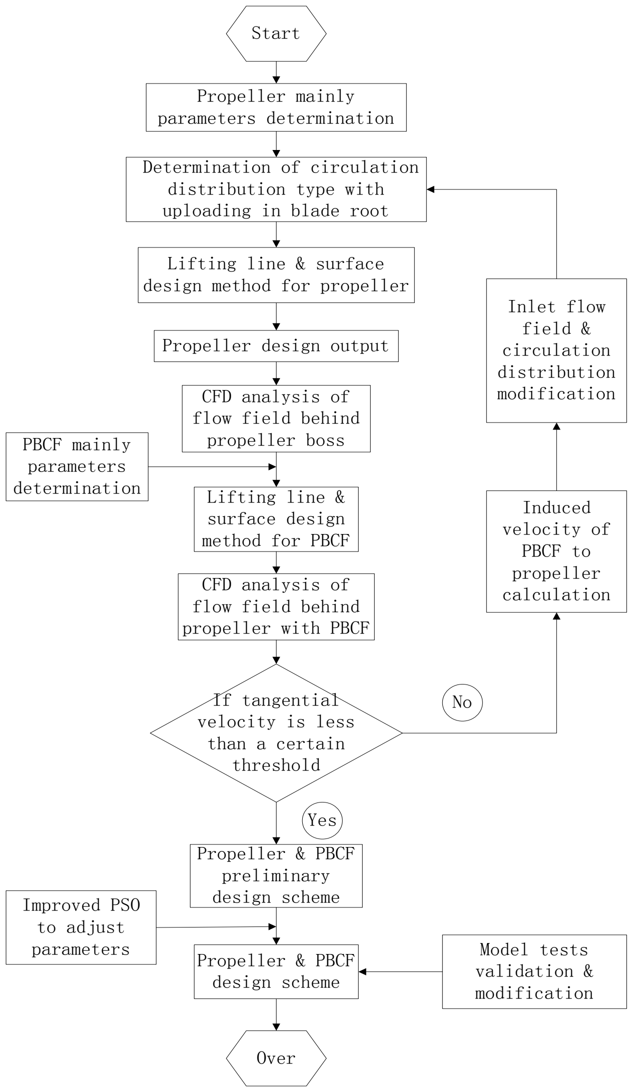


Figure 2 Flow chart of design procedure

4.2 Model test validation

To validate the energy saving effect of the integrative design method, the "reverse POT” (Propeller Open Test) (22nd ITTC 2000) is conducted in the cavitation tunnel of Shanghai Jiao Tong University (SJTU). The tests are carried out both with and without PBCF for scheme A and B.

Figure 4 shows the comparison of hydrodynamic performance between scheme A and B for both with and without PBCF. Results of model tests indicate that propulsive efficiency gains can reach to 2.9% for case scheme A while 4.1%for case scheme B in design condition (around J=0.44). The propeller and PBCF scheme B designed by the integrative method has higher efficiency than the scheme A designed by the 'PBCF matching fixed propeller' method in a wide various of advance coefficient.

Model cavitation test results show that, both scheme A and B can break up the hub vortex. Figure 5 shows the comparison of cavitation visualization results between the original propeller without PBCF and the design scheme B. It can be seen that the hub vortex disappears in the case of scheme B, moreover, in the heavy loaded working condition (J=0.30), the hub vortex does not generate yet. Therefore, it can be concluded that the propeller and PBCF of scheme B match well, and the integrative design method is effective and reliable.

Table 1 Comparison of parameters of scheme A & B

SCHEME	PARAMETER	SCHEME A	SCHEME B
Propeller	Diameter(m)	5.5	5.5
	Blade number	3	3
	$(P/D)_{0.7R}$	0.8058	0.7865
	$(P/D)_{0.2R}$	0.7202	0.8601
	Area ratio	0.85	0.85
PBCF	Installed angle	46	49
	Fin number	3	3
	Radius ratio (Rf/R)	0.28	0.28

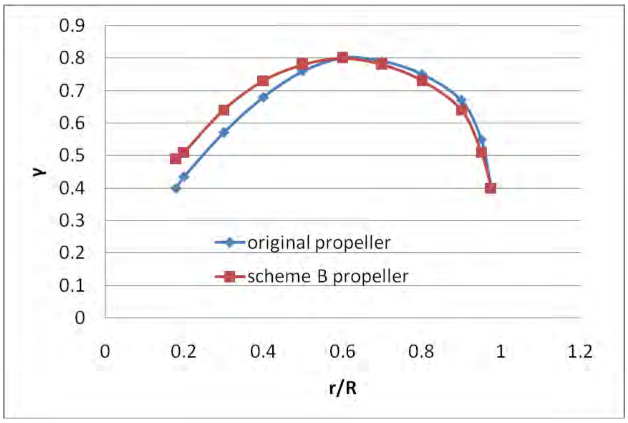
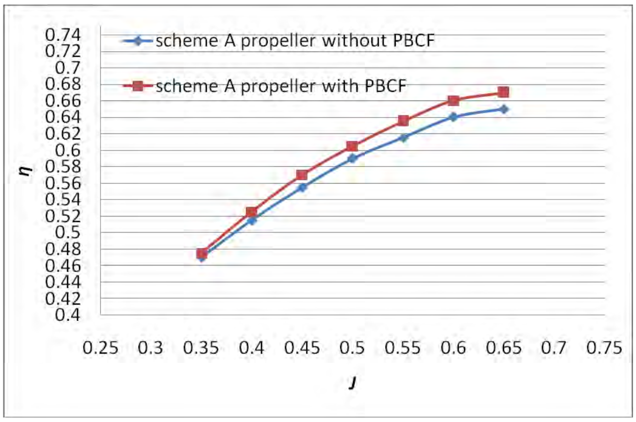
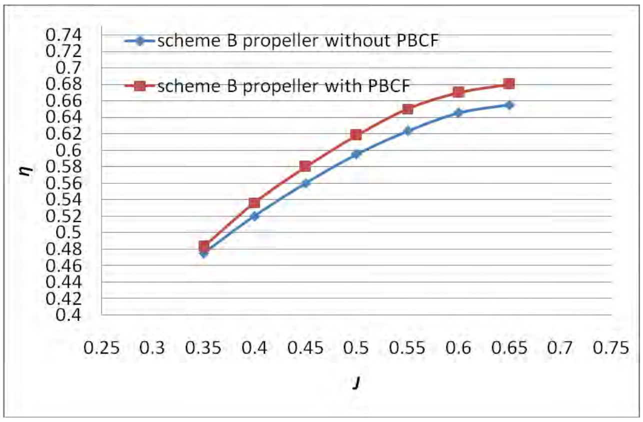


Figure 3 Circulation distribution of propellers

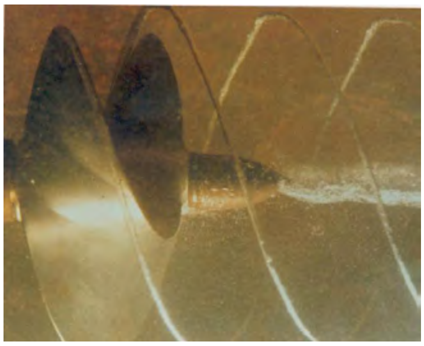


(a) Scheme A

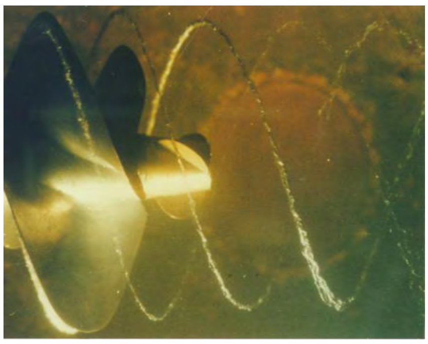


(b) Scheme B

Figure 4 Comparison of hydrodynamic performance between scheme A & B



(a) Original propeller



(b) Scheme B propeller with PBCF

Figure 5 cavitation visualization results

5 CONCLUSION

In order to consider the interaction between PBCF and propeller sufficiently, and dig the energy saving potential of PBCF to the utmost extent, in this paper, an integrative propeller and PBCF design method including theory design and numerical optimization design is presented. The design method is based on the concept of uploading in blade root, lifting line and lifting surface theory, CFD tools, improved particle swarm optimization algorithm, and model tests research.

The model test results show that the propeller and PBCF designed by the integrative method has higher efficiency, and this method is effective, reliable and practical.

Wishfully, the integrative design method provided in this research can be helpful for further research and study on 'EEDI standard' or 'green propulsion'.

REFERENCES

22nd ITTC. (2000). Report of the Specialist Committee on Unconventional Propulsors. pp.2-3.

CAI Haopeng, SU Yumin, ZHANG He. 'A Particle Swarm Optimization Algorithm with Partial Mutation Strategy and its Application'. (2009). IEEE International Confence on Intelligent Computing and Intelligent Systems, Shanghai, China.

HU Zhian, ZHOU Hanren. (1991). 'A Method of the Characteristic Calculation and Shape Decision for Propeller Boss Cap Fins'. Journal of Hydrodynamics(Ser.A) **6**(3), pp.103-111(In Chinese).

LI Pengcheng. (2012). Design Method of Propeller Boss Cap Fin. Dissertation of China Ship Scientific Research Center(In Chinese).

OuchiK, OguraM, KonoY, et al. (1988). 'A Research and Development of PBCF(Propeller Boss Cap Fins)-Improvement of Flow from Propeller Boss'. Journal of Society of Naval Architects of Japan **163**, pp.66-78.

OuchiK, TamashimaM, KawasakiT, et al. (1989). 'A Research and Development of PBCF(Propeller Boss Cap Fins)-2nd Report: Study on Propeller Slipstream and Actual Ship Performance'. Journal of Society of Naval Architects of Japan **165**, pp.43-53.

TakeoN, NorioI, HisashiK. (2010). 'Energy Saving Technology of PBCF(Propeller Boss Cap Fins) and its Evolution'. IPS'10, Okayama, Japan.