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Using the Propeller Pre-Swirl Stator to Reduce Underwater Vehicle Roll Motion and Increase Propeller Efficiency

H. Bahrami [1], A. Nadery[1], A. Moghaddas Ahangari [2]*, H. Ghassemi[1]

[1] Department of Maritime Engineering, Amirkabir University of Technology, Tehran, Iran.
[2] Imam Hossein University, Tehran, Iran.

ABSTRACT: Pre-swirl stators can operate as a device to improve the hydrodynamic performance of the propeller and reduce the excess propeller torque on the underwater vehicle. This excess torque on the underwater vehicle with a circular cross-section can cause harmful rolling motion. The most important and influential parameters in the design of these stators are the chord length, distance from the propeller, and angle of attack. In this paper, these parameters are investigated using the Taguchi method and stator design to simultaneously reduce the underwater vehicle roll motion (reduction of excess propeller torque) and increase propeller efficiency using computational fluid dynamics with the help of commercial software STAR-CCM+. To validate the calculations, the numerical simulation results of a B-series propeller are compared with the existing experimental test, the numerical results are obtained with less than ten error percentages compared to the experimental results. The Grid Convergence Index has also been used to ensure the independence of the results obtained from the mesh. The final stator designed in this paper reduces the total propulsion torque by 44.47% compared to the non-stator mode and improves efficiency by 2.29%. Also, the designed stator reduces the vortex of the blade tip and the propeller hub.

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1- Introduction

One of the most important hydrodynamic parameters of underwater vehicles is keeping track of the determined path. Since the rotation of the propeller creates a torque around its axis, this torque can cause a rotational motion around the longitudinal axis of the underwater vehicle. Stators can be used in two positions in front of the propeller (upstream) and behind the propeller (downstream). The stators placed in front of the propeller are called pre-swirl stators.

Table 1 shows the advantages and disadvantages of pre-swirl stators.

Much research has been done on the pre-swirl stators design of surface vessels with the view of increasing the efficiency of their propulsion system. But so far, no research has been done on the design of subsurface pre-rotating stators with the view of simultaneously reducing the torque and increasing the efficiency of their propulsion system.

2- Methodology

To reduce simulation solving time, two separate simulations as shown in Fig. 1 have been used to check the stators. In the first simulation of Fig. 1 (a), the underwater vehicle simulation has been performed as self-propelled without a stator at the desired speed, and the input speed profile (input velocity) shown in the figure has been saved.

Table 1. Advantages and disadvantages of the pre-swirl stator

Pre-swirl stator	
Advantages	**disadvantages**
Recovers rotational energy losses by creating rotation in the opposite direction of the propeller [1]	Additional drag [2]
quieter thrust due to the removal of vortices before entering the rotor [3]	Lower efficiency compared to post-swirl stators [2]
The lower speed of current on these stators compared to post-swirl stators, so they work more slowly [2]	Rotating output current
Creating a torque opposite to the propeller torque to remove the instability of the underwater vehicle torque [4]	Weakening of propeller cavitation performance [2]
Creating more loading on the propeller compared to post-swirl stators [3]	-

*Corresponding author’s email: gasemi@aut.ac.ir

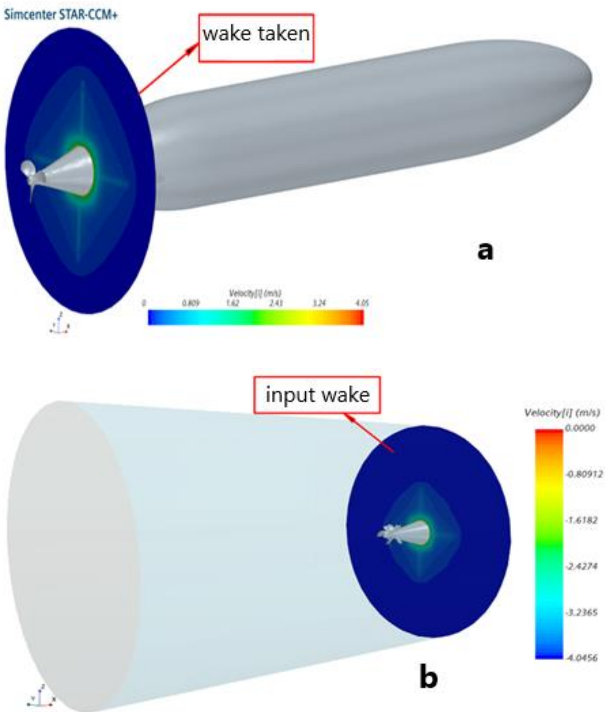

Fig. 1. Two-part simulation of the underwater vehicle to examine the stator: (a) The first simulation of the self-propulsion underwater vehicle to obtain the velocity distribution (wake), (b) The second simulation of the rear part of the underwater vehicle with

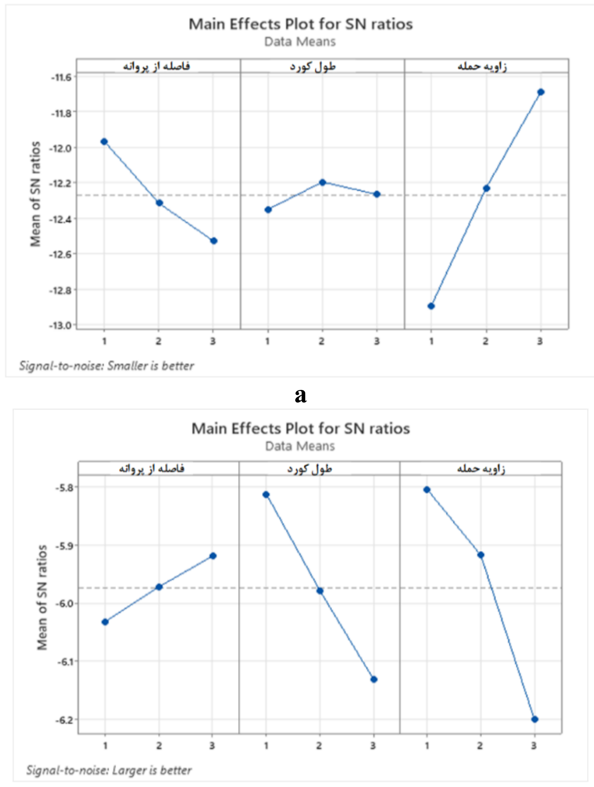

Fig. 2. Taguchi signal-to-noise ratio: (a) in terms of minimum torque (b) in terms of maximum total efficiency

Then, this speed profile has been used in the second simulation of Fig. 1(b) as an input to the simulation of the rear part of the subsurface along with the stator and rotating propeller.

Results and Discussion

Fig. 2 shows Taguchi's results in terms of minimum torque and maximum efficiency.

It can be seen in

Fig. 2 that if the stator is located at the closest distance from the propeller (0.39*R*) and the chord length is 0.65*R* and has If the angle of attack is 17.5 degrees, the total torque value is reduced by 44.47%, and the remarkable thing is the simultaneous increase in the efficiency of the propulsion system, which is improved by 2.29%. In the maximum efficiency mode, the efficiency value has increased by 8.26%, but the total torque value has decreased by 30.82%. So, if you need more efficiency, you can use the maximum torque mode and by spending 13.65% of the total torque, you can increase the efficiency by 5.97%. What is important is the power delivered to the propeller, without the stator, the power delivered is 819.32W, while with the use of the stator, the power value is equal to 800W, that is, it has reduced the engine power by 2.3%.

3- Discussion and Comparison

The stator was designed from the results of the Taguchi method in terms of the minimum total torque which reduces the torque value by 44.47% and the efficiency of the propulsion system has increased by 2.29%. It is selected as the most optimal stator, and in this section, its performance behind the vehicle is compared and discussed with the condition without a stator.

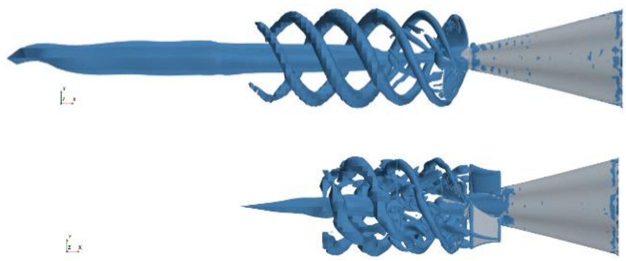

Fig. 3. Distribution of vorticity with Q= 1000 s^{-2} criterion, top: without stator and bottom: with the stator

Fig. 3 shows the velocity of the flow and the vortex created in the tip and hub of the propeller and the distribution of the propeller vortex with the *Q* criterion, behind the subsurface in the state with and without the designed stator. It can be seen that the designed stator reduces the vortex created in the tip and hub of the propeller.

4- Conclusions

In this article, the design of the pre-swirl stator for the underwater vehicle has been discussed with the view of simultaneously reducing the torque and increasing the efficiency of the propulsion system. In the first part of this article, in order to validate the simulation of a B-series propeller, it has been simulated in STAR-CCM+ software and the obtained results have been compared with experimental data. The simulation results have been obtained with an error percentage of less than 10% compared to the experimental data. In the following, the design of the stator has been discussed in order to reduce the produced torque without reducing the efficiency of the propulsion system. Based on the obtained numerical calculations, the following results have been obtained:

• The final designed stator has reduced the amount of torque input to the body by 44.47% and also improved the efficiency of the propulsion system by 29.2%.

• The average propulsive force and oscillating torque of the propeller in one rotation cycle shows that by using the stator if the rotation speed of the propeller is the same, the amount of propulsive force increases by 21.4%, and the amount of torque increases by 29.6%.

• Based on 9 simulations performed by changing the rotation speed of the propeller, in all cases the total propulsion force is almost the same and equal to 135.8 newtons.

• The important result is related to the power delivered to the propeller, without the stator and with the stator, the power delivered to the propeller is equal to 819.32 watts and 800 watts, respectively, which has finally led to a reduction of 2.3% of the engine power.

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