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Research and Simulation of a flexible robotic fish tail fin propulsion system

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Abstract. This article uses a flexible crescent caudal fin tuna as the research object, sets up the robot fish physical model ,researches the propulsion and advancing speed of the model, discusses forward speed, sliding and swing amplitude, frequency and phase to the flexible tail fin propulsive performance, and uses MATLAB to simulate, motion simulation is consistent with the way to achieve the real movement of the fish.

Keywords: Flexible tail fin, Robotic fish, MATLAB simulation.

Introduction

Biologists found that in all ocean species, the efficiency of fish swimming mode is the highest. Through thousands of years of evolution, fishes have had an amazing swimming ability, high mobility, high hidden features. More and more Chinese and foreign scientists carried out research on ROBOFISH, trying to study the promoting mechanism of fish to implement a propeller which has movement equally efficient, high mobility, high hiding like fish imitation.

Based on previous studies, this article uses a flexible crescent caudal fin tuna as the study object,adds to the chord and spanwise deformation, and establishes a physical model ,researches and analysises the robot fish propeller thrust and speed of by MATLAB simulation, in order to get the motion parameters of thrust, efficiency and function.

1 Robotic fish tail fin model

Robot fish tail fin tuna model references the caudal fin shape (Figure 1). The shape of caudal fin tuna in the center is approximately NACA0015, in the end of the shape is approximately NACA0009. Therefore, this article uses NACA0015 airfoil in the middle of the caudal fin sectional robotic fish , uses at NAC0009 airfoil at the end , uses NACA0012 airfoil in the middle . Caudal fin dimensions shown in Figure 2, chord C = 35.22mm, exhibition length B = 130, sweep $\alpha = 47°$.

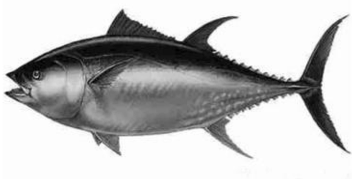

Fig. 1 Tuna caudal fin shape

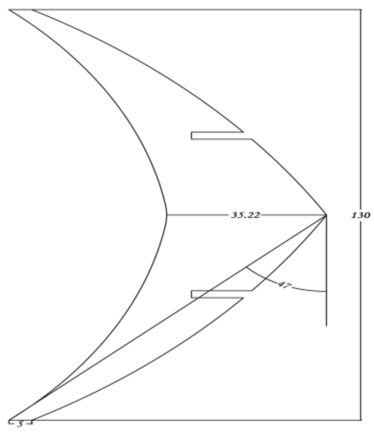

Fig. 2 Robotic fish fin size

1.1 Tangential deformation equation

Pengfei Liu proposed equations (1) tangential deformation equations shown in his article: δ_c is the string to the magnitude of the deformation, it is the product of tangential deformation factor δ_{c0} plus features of the chord length C_0. Namely; $\delta_c = \delta_{c0} C_0$; ε are 1.5,2,2.5,3,3.5,4 values respectively; Φ_c is a chord relative phase angle to traverse the caudal fin deformation, usually negative. Eq. (1) represents a chord deformation begins at the end of chord characteristic C_0, that is the Central point to the trailing edge deformation, while the leading edge to the midpoint of the deformation.

$$z = \delta_c (2x-1)^{\varepsilon} \sin(2\pi ft + \Phi_c) \quad x \geq \frac{1}{2}$$

(1)

On this basis, we can extend equations (1) to any point on the chord to the trailing edge deformation occurred, and the leading edge to the point is not deformed, the deformation equation of formula (2) below,in it 1<s<∞; $x \geq \frac{1}{s}$; $\varepsilon > 1$.

$$z = \delta_c \left[\frac{s}{s-1} x - \frac{1}{s-1} \right]^{\varepsilon} \sin(2\pi ft + \Phi_c)$$

(2)

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When s is larger,the deformation is closer to the leading edge; when ε is greater,the distortion is flatter near the leading edge , and the more intense near the trailing edge of the Transfiguration. When S=2, the equations (2) turns into the equations (1). Take $\delta_{c0} = 0.1$, in Figure 3s=2, respectively to take ε =1.5,2,2.5,3,3.5,4, when it is the maximum chord deformation; In figure 4 ε = 1.5, s is taken chordwise 2,3,4 maximum deformation.

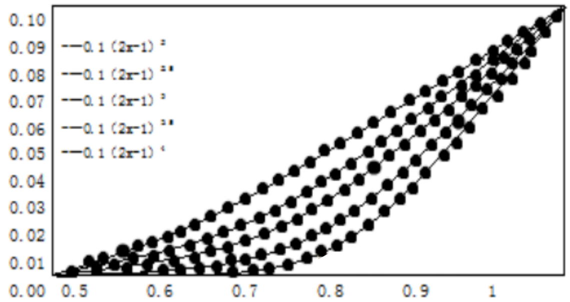

Fig. 3 Chordwise deflexion shapes of half chord length

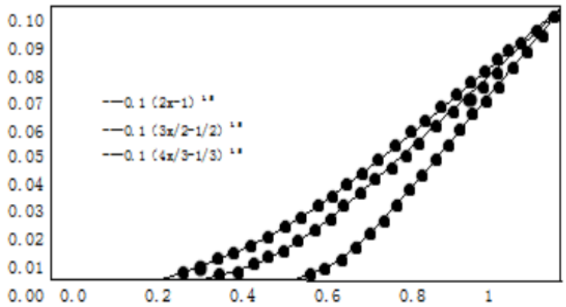

Fig. 4 Comparison of chorodwise deflexions

We assume that each interface of the caudal fin deform by the equations (2), leading edge is with no deformation , at the trailing edge it occurs maximum deformation . Also, because the deformation of the caudal fin, tail fin generates the relative speed between the bin ,which is determined by the time derivative of the equations (2). And after appropriate coordinate transformation, the speed should be the overall speed of the caudal fin at a point. In this way, calculating for each step time , the influence coefficient of each bin should be recalculated.

1.2 spanwise variable equation

Using the cantilever beam uniform deformation equations Pengfei Liu proposed based on evenly distributed load, such as equations (3), in it δ_s is spanwise deformation magnitude ,which is the product of the spanwise deformation factor δ_{s0} plus semi span l, that is $\delta_s = \delta_{s0} l$; ε should be greater than zero, and the greater the deformation near the strings more gentle, and more intense deformation near the wingtip; Φ_s is the phase angle of spanwise deformation to the tail fin traverse , usually negative. In equations (3) the number ±and the absolute value is produced by different about half the value of the symbol of the span y.

$$z = \delta_s \left[2(\frac{y}{l})^2 - \frac{4}{3}(\frac{y}{l})^3 + \frac{1}{3}(\frac{y}{l})^4 \right] \left| \frac{y}{l} \right|^{\varepsilon} \sin(2\pi f t + \Phi_s)$$

$$\varepsilon \geq 0 \quad (3)$$

Suppose each tangential cross-sections of caudal deforms according to equation (3), string with no deformation, deformation of the tip is the largest. The relative velocity of spanwise deformation between the tail fin of each bin is produced by the equation (3) with respect to time to determine ,that is the total velocity of a point on the tail fin, and at each step time recalculating the influence coefficient.

After given to the chord of caudal fin and spanwise deformation equation, you can determine the location of any of the caudal fin in a time profile,set up the caudal fin is constant thickness after deformation, you can determine the shape of the deformed tail fin after deformation. In it , the tangential deformation parameters respectively are δ_{c0} = 0.1, s = 2, ε = 1.5 , $\Phi_c = -\pi/2$; spanwise deformation coefficient δ_{s0} = 0.1, ε = 0, $\Phi_s = -\pi/2$. Under normal circumstances, when the tail fin traverse zero, spanwise and chordwise deformats the largest, and their phases are lagging behind the traverse, so we take $\Phi_c = \Phi_s = -\pi/2$.

Tail fin motion parameters respectively are 为 $A_Z = C_0$, $\theta_0 = 20°$, $f = 0.5Hz$, $\varphi_0 = \pi/2$. Tangential deformation parameters: δ_{c0} =0.1 , s=2 , ε =1.5, $\Phi_c = -\pi/2$; Spanwise deformation parameters: δ_{s0} =0.1, ε =0, $\Phi_s = -\pi/2$.

2 The flexible fins forward speed simulation

Because of the force of water, under normal circumstances the fin from root of the connection to the top of does not exhibit linear form, there will be a longitudinal bending. We assume that the water is evenly distributed load forces to establish a flexible fin geometry fluctuations. Take a point in the X axis , through point A parallel to do OYZ plane, the plane can be obtained online with flexible fins deflection surface, namely the deflection lines (Figure 5).

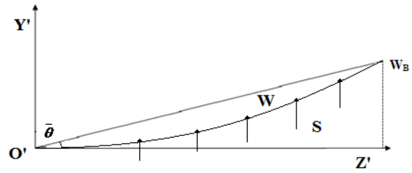

Fig.5 The deflection curve of section of fish fin

From the deformation formula of mechanical beam ,it is shown that the deflection line of flexible fins on OYZ plane can be represented by the formula (4), in it L is the length of the fin; E is the modulus of elasticity of the fins; I is the corresponding moment of inertia ; q is the fin surface uniformly distributed load to bear.

$$w = \frac{qz^2}{24EI}(z^2 - 4Lz + 6L^2)$$
(4)

Its end Deflection :

$$w_B = \frac{qL^4}{8EI}$$
(5)

Then q can be expressed as:

$$q = \frac{8EI}{L^4} w_B$$
(6)

So the fin deflection line can be expressed as:

$$w = \frac{w_B z^2}{3L^4}(z^2 - 4Lz + 6L^2)$$
(7)

w_B is the deflection of the curve in the ends of the fins and

$$w_B = |A\sin(kx)|$$
(8)

Under the flexible fins conditions,you can define nominal angle

$$\bar{\theta} = \arcsin\frac{w_B}{L}$$
(9)

In the case of a small deflection, it can be approximated that $z_0 = L\cos\bar{\theta}$ .In figure 5 the area S is enveloped of fins curve, the dotted line and Z 'axis :

$$S = \int_0^{z_0} \frac{w_B z^2}{3L^4}(z^2 - 4Lz + 6L^2)dz$$
$$= \frac{w_B}{3L^4}\left(\frac{z^5}{5} - Lz^4 + 2z^3L^2\right)\Bigg|_0^{L\cos\bar{\theta}}$$
$$= \frac{w_B}{3}\left(\frac{\cos^5\bar{\theta}}{5}L - L\cos^4\bar{\theta} + 2L\cos^3\bar{\theta}\right)$$
(10)

The quality of water Fins enveloping is:

$$M_{water} = \frac{\rho}{3}\int_0^{\lambda} |A\sin(kx)|\left(\frac{\cos^5\bar{\theta}}{5}L - L\cos^4\bar{\theta} + 2L\cos^3\bar{\theta}\right)dx\ )$$
$$= \frac{4}{15k}\rho AL\sin^2\left(\frac{k\lambda}{4}\right)(\cos^5\bar{\theta} - 5\cos^4\bar{\theta} + 10\cos^3\bar{\theta})$$
(11)

The flexible fins parameters can be set: a longitudinal length of the fin L = 0.2m; wavelength λ = 0.314m; fluctuation angular frequency $\omega = 2\pi$. Then you can substitute them into the formula (11), runs on MATLAB, obtain the results shown in Figure 6.

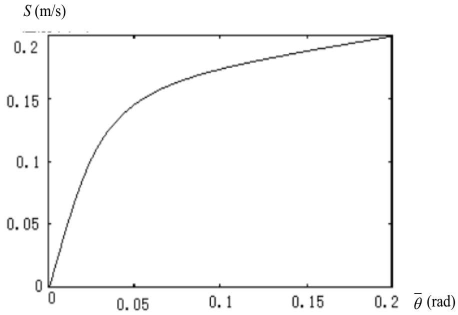

Fig.6 The changes of soft fin thrust velocity

3 Conclusions

(1) using the momentum theorem and over propeller theory, we can establish the relationship between the caudal fin propulsion and motion parameters, obtain the estimation method of caudal fin propulsion.

(2) Flexible crescent-shaped caudal fin propulsion mode is a novel way and can be used for micro and underwater diving underwater robots and other propulsion system.

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