A MATHEMATICAL ANALYSIS FOR DESIGN AND DEVELOPMENT OF RUDDER (BIOLOGICAL INSPIRATIONAL) FOR SMALL FLOATING AND FISHING VESSEL

Sivakumar Mayilsamy
Department of Basic Engineering, Tamil Nadu Fisheries University, Nagapattinam, India

Jayakumar
Department of Mathematics, SNS College of Engineering, Coimbatore

Mohammad Tanveer
Department of Aquacultural Engineering, College of Fisheries Engineering,
Tamil Nadu Fisheries University, Nagapattinam, India

Abstract

The small-scale self-propelled ship model with the Z-test for the performance verification of rudder plays an important role to study and understand the waterway transportation and it reduces the cost incurred in real life situations. This study aims at testing the Bio – Inspired rudders for the replacement of regular rudders used in fishing vessels. The conceptual design is based on the universally accepted Z-test and optimized turning quality index (K) and turning lag index (T) for its maneuverability with the newly developed Bio-Inspired rudder model as simplified in time parameters associated with ship movement. Therefore, in this paper a conceptual approach for design and development of Bio-Inspired rudder has been discussed.
Keywords: *Z- test, turning quality index-K, turning lag index-T, Bio - Inspired rudder*

Introduction

The International Maritime Organization (IMO) regulated the Energy Efficiency Design Index (EEDI) for the ship building in order to reduce the CO_2 emissions from ships. EEDI is the CO_2 emitted per transporting 1 ton of cargo for 1 mile [g·CO2 / ton·mile]. [1]. This EEDI being the important index of comparison for the ships performance.

The gained propulsion through a rotating propeller of any vessel will be lost in the form of residual swirl energy at the back of the propeller which is not a desirable characteristic of a good mode of transportation. This residual swirl can be retrieved as a thrust for the ship by providing some Energy saving design. This is the base behind which a Bio-Inspired rudder came in place of replacement for the normally employed rudders for Fishing and also for the transportation vessels. These Bio-inspired rudders may tap the swirl energy of propeller slip stream through decreasing the viscous loss behind the propeller hub (in other words lowering the eddies generated between hub and rudder) as an enhancement of thrust for the ship. This in turn increases the speed performance and reduces the fuel consumption for per kg load transported.

Z- Test

The governing equations are the continuity and the Navier-Stokes equations of unsteady state turbulent flow. The turbulence model applied to the ship on Z- test is the Reynolds stress model. The computations are carried out at towing and self-propulsion conditions.

Traditional Z- test steps are:

- To maintain constant voyage with stated speed.
- Turn the rudder right at 10° and maintained when the angle of ship head turn left to maximum at 10°.
- Turn the rudder left at 10° and maintained when the angle of ship head turn right to maximum at 10°.
- Thus, the same procedure has to be repeated for the required number of times to avoid manual error. In the process of the test, the time of the rudder angle reached, the designated position, the characteristics time of turning head (δ-t) and the angle of inertia exceed (ψ-t) should be recorded and draw the curve.

The angle of inertia exceed is the difference between the instantaneous angle steering opposite rudder and the maximum heading angle. The lag time of turning head (T) refers to the time intervals between the instantaneous times of the rudder passing the reference (0°) to the maximum turning angle.

Bio-Inspired Rudder models

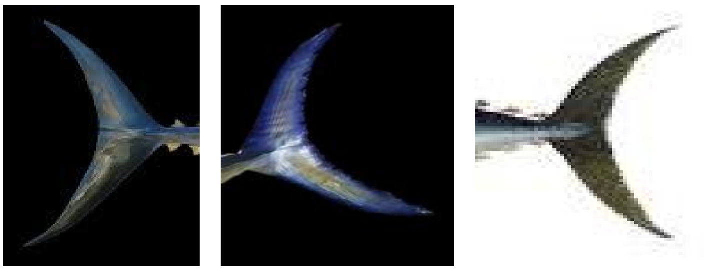
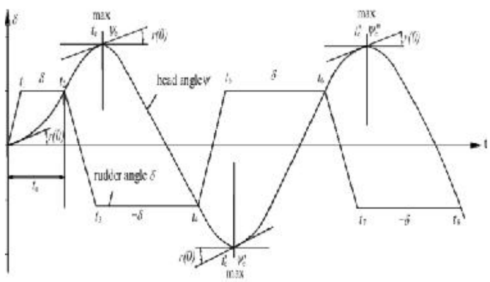


Figure 1. Caudal fin of Mackerel, Emperor and Tuna

System Modeling and Optimization



From the test results and through the curves δ-t, ψ-t, the values of K and T will be approximated based on the following formulae.

$\Psi(t_e) = K_4 = K \int_0^{t_e} (\delta dt)\ K\delta_r t_e$

$\Psi(t'_e) = K_6 = K \int_0^{t'_e} (\delta dt)\ K\delta_r t'_e$

$\Psi(t''_e) = K_8 = K \int_0^{t''_e} (\delta dt)\ K\delta_r t''_e$, and $K = \frac{1}{2}\{ K_{6,8} + K_4)$, $T = \frac{1}{2}\{ T_4 + \frac{1}{2}(T_6 + T_8)$

The calculated values of the K and T were optimized using the following optimization

$M\bar{V}_x - MV_x \cos \Psi = F_x T_{\Psi x}$, $M\bar{V}_y - MV_y \sin \Psi = F_y T_{\Psi y}$: $T_\Psi = (T_{\Psi x}^2 + T_{\Psi y}^2)^{1/2}$

$MV_x - MV_x \text{ Cos } \delta = F_x T_{\delta x}$, $MV_y - MV_y \text{ Sin } \delta = F_y T_{\delta y}$: $T_\delta = (T_{\delta x}^2 + T_{\delta y}^2)^{1/2}$ and also with $K = (T_\Psi + T_\delta) / 2 = 1 + (T_\delta / T_\Psi)$

$MV_x - MV_x \text{ Cos } \beta = F_x T_{\beta x}$, $MV_y - MV_y \text{ Sin } \beta = F_y T_{\beta y}$: $T_\beta = (T_{\beta x}^2 + T_{\beta y}^2)^{1/2}$ and $T = T_\beta / T_\psi$
where,

ψ - the ship heading angle, δ - the rudder angle, β - ship drift angle

V - the velocity vector of ship of gravity

T_ψ- the time for ship turning the angle ψ

T_δ - the time for rudder turning the angle δ

T_β - the time for drifting the angle β.

Error analysis based on the parameters; ψ, δ, β, V, T_ψ, T_δ, T_β will be carried out for the verification of the proposed Bio-Inspired rudder and used for the comparison of the performance evaluation of the fishing vessel. The following method is used for the purpose.

$y = f(x_1, x_2, x_3, \ldots x_n)$

where, y - experimental values,

$x_1 \ldots x_n$- optimized values

Taylor series of expansion will be used as an easy solution for this analysis.

Advantages

- Reduced emission of green house gases for the same per kg load transported.
- Increase in thrust with same fuel consumption.
- It offers decentralization of power.
- It minimizes environmental pollution.
- It is absolutely maintenance free and having low cost of operation.

Limitations

- Initial investment may be considerably high.
- Obtaining the natural curve requires a cutting edge technology.
- Only feasible with mass production (Particularly Molding).

Conclusions

The adoption of this newly proposed Bio-Inspired rudder needs a huge amount of popularization. The fisherman needs an intense communications to avoid misconception and to accelerate the execution of the technology. The technology transfer needs involvement of industrialists who understand people and their needs with the real life conditions along with the nature and infrastructure in developing countries as discussed by Murai (2000). Thus, the newly proposed Bio-Inspired rudders will provide an excellent platform for the fisherman community in terms of profit and economic growth throughout the country.

Acknowledgement

The authors are thankful to College of Fisheries Engineering, Tamil Nadu Fisheries University for motivation towards research.

References

1. Murai, S. (2000). Technology transfer for sustainable development in developing countries. *International Archives of Photogrammetry and Remote Sensing*. Vol. XXXIII, Part B6. Amsterdam.
2. Jung-Hun Kim1, Jung-Eun Choi, Bong-Jun Choi1 and Seok-Ho Chung. (2014). Twisted rudder for reducing fuel-oil consumption. *International Journal of Naval Architexture and Ocean Enggneering*.(2014) 6:715-722.
3. Kyoungsoo Ahn, Gil-Hwan Choi1, Dong-Igk Son and Key-Pyo Rhee. (2012). Hydrodynamic characteristics of X-Twisted rudder for large container carriers. *International Journal of Naval Architexture and Ocean Enggneering*. 4:322-334.
4. CAI Chuang, ZHAO Chuan-bo, CAI Xin-yong. (2012). Optimization Calculation on Maneuverability Index of Small Scale Ship Model, *International Conference on Modern Hydraulic Engineering. Procedia Engineering*.28: 813 – 819.
5. Dae Won Seo1, Seung-Hee Lee1, Hyo Chul Kim and Jung Keun Oh. (2010). A Numerical study for the efficacy of flow injection on the diminution of rudder cavitation. *International Journal of Naval Architexture and Ocean Enggneering*. 2:104-111.
6. H.J. Prins, M.B. Flikkema, B. Schuiling, Y. Xing-Kaedin, A.A.M. Voermans, M. Müller, S. Coache, T.W.F. Hasselaar and S. Paboeuf. (2016). Green retrofitting through optimisation of hull-propulsion interaction – GRIP. *Transportation Research Procedia*. 14 : 1591 – 1600.
7. Li Xiaobiao. (2003). Simulation of the test data of the velocity of ship model. *Journal of the Yangtze river academy*. 16 (3). 7 - 9.
8. Hong Biguang,YuYang. (2000). Statistical analysis on K、T index on ship maneuvering[J]. *Journal of dalian maritime*. 26 (4) : 29 ~ 33.
9. CAI Chuang ,CaiRuZhe. (2005). Experimental study on navigation of ship model of regulating the risks Beaches of Yangtze river. *Journal of Chongqing jiaotong University*. 5 : 135 -139.
10. Choi, J.E., Kim, J.H., Lee, H.G. and Park, D.W. (20100. Hydrodynamic characteristics and speed performance of a full spade and a twisted rudder. *Journal of the Society of Naval Architects of Korea*.47(2):163-177.