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A Review Paper: On Design and Analysis of Propeller of Underwater Vehicle

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Abstract—*To observe the various underwater circumstances and control over the sea a lot of research work has done on an underwater vehicle for last few years. One of most important part of underwater vehicle is propeller. This paper is written with the aim to understand various important aspects of underwater vehicle propeller design. This review primarily focuses on a brief idea of mechanical property analysis of propeller. A bunch of paper discussed on hydrodynamic characteristics and various optimization methodologies of the propeller design. Through the application of CFD, CATIA, Pro-Engineering model development and simulation have done. Matlab also help in developing mathematical model and to get its solution. Experimental works also done and its results are compared with the computer simulation result and evaluate it. Besides that power system, propulsion mechanism, control strategy, fabrication procedure, etc. also investigated from different point of view. This paper comprehensively covers design, manufacturing, hydrodynamic, acoustic characteristics and tried to create an interrelationship and try to find out various field still remain to work the in future. Maximum researcher tries to improve propeller efficiency with the minimum fuel consumption with maximum durability and less stress generation.*

Keyword*: propeller, propeller design, acoustic response, hydrodynamic characteristics, propeller efficiency, propulsion mechanism.*

1. INTRODUCTION

Design of propeller is generally done to achieve a operational condition for a particular velocity of advance and rpm, where it delivers the maximum hydrodynamic efficiency with less power consumption [1]. In the advance time of science and technology it becomes an important issue to observe our non traditional resources as a source of energy and other important platform. One of such important field is underwater platform of sea. For that a lot of research works have been doing to develop under water vehicles and to observe its various effect. Autonomous Underwater Vehicles (AUV), also known as unmanned underwater vehicles, can be used to perform underwater survey missions such as detecting and mapping submerged wrecks, rocks, and obstructions and collecting the seabed information for commercial and research purpose.

The propeller is likely to work in off-design conditions (straight ahead course) and consequently, in addition to propulsive loads (thrust and torque), in-plane loads appear, which further stress the shafting equipment and the stern hull structure. During the design of propeller, its blade strength become a great issue for it's functionally and efficiency. The stress analysis and other study like hydraulic and mechanical behaviour of propeller are quite difficult task due to its complex geometry. [5] Now a day's composite materials are getting preference in instead of conventional metallic metal due to light weight, long durability and high effectiveness and economic healthy[2]. In this review paper various aspects of underwater vehicle are discussed based on different research field. Among them propulsion system, optimization of design, thermal analysis etc are some important field.

2. LITERATURE REVIEW

Y.S Rao and B.S.Reddy [2] shows composite propeller blades are safe in case of resonance phenomena in their harmonic analysis. Vibration defect can also be controlled in case of composite as damping effect is more. They had done a comparison of harmonic analysis using ansys software between aluminium metal and S_2 Glass fabric/Epoxy. From their result maximum displacement in case of composite is 0.08192 which very less than aluminium propeller blade 0.1784. M.A.Khan et al[3] observed inter laminar shear stress for composite material considering different no of layer and shows there is strong bonding between the layers. Eigan value analysis shows composite material has 80.5% more natural frequency than aluminium propeller. In their static analysis they had shown composite consist of separate layer. V Ganesh et al. [4] had done static and modal analysis for aluminium propeller and composite (carbon reinforced plastics) propeller. From their analysis it shows blade deflection in case composite propeller is very less compare to aluminium. Besides that they also observed the stress strain variation for the strength analysis. K.B.Yeo et al.[5] done some prediction about the stress distribution around a propeller blade through finite element method. Considering wagenigen B Series 3 bladed propeller and stainless steel as material hydrodynamic analysis carried out. With a increasing rotational speed developed stress also increase and after 3000 rpm it cross it critical stress and chance of failure may occurs. E.A. De Barros and J.L.D.Dantas [6] proposed a model for the measurement of hydrodynamic force and momentum through CFD simulation. Their prediction value compare with the experimental data. Their simulated results show that wake coefficient is 0.36 where as experimental results shows 0.22. W.Y.San et al. [7] given a numerical prediction based on CFD, FEM and BEM for submarine structure about its propeller excited acoustic response. Unique solution obtained by applying boundary condition in Refined Integral Algorithm and pointing the CHIEF points normal to the interior field. Field point is calculated by global mesh refinement scheme considering QUAD8 as a boundary element. Error refining have done up to 10^{-4} maximum limit. In BEM model of sphere RIA applied for HIE integral calculation. Open water characteristic of 4381 propeller investigated by CFD and experimental result compare with achieve result. "Sub marine + propeller" system was simulated by CFD to get propeller variation of torque and thrust. SST turbulent model developed to observe flow details in boundary of the submarine. B. G. Paik et al. [8] compared the performance characteristics of flexible propellers based on different fabrication. Three models made of cutter Carbon/epoxy and glass/epoxy tested in medium size cavitations tunnel of MOERI. The thrust produce in the blade and advance ratio variation are responsible for the flexibility of the propeller because it reduce the pitch angle of the blade. The relation of the produced thrust and sound pressure observed from acoustic noise measurement test. Tailoring method done for effective control with TiO_2 as tracer particle. Blade flexibility effect on propeller wake was observed by Particle image velocimetry (PIV) technique. C Georgaides et al. [9] proposed a design of a underwater hexapod robot which is propel by paddles. The main aim was characterized the forces generated by the paddle oscillating in water. For that a paddle trajectory based on cubic spline developed. Here the thrust produce depends on the inflow estimation which is done by replace volume of water by the paddle. An experimental set up is done for thrust measurement. Experimental data collection and control of paddle is done by Lab VIEW program. The vehicle moving in a stationary body of constant properties, translation motion following Newton's equation and rotational motion Euler's equation are some assumption. For better understanding 3ds max®, a graphic and animation software used for animation purpose. O. Barannyk et al. [10] experimentally investigated the propulsion system of a oscillating flexible plate with the combination effect of heave translation and pitch rotation. The motivation comes from caudal area of a fish and goal gain through a no. of experiment at different depth of submerge and measuring the force. A flat rectangular plate with blunt leading and tailing is consider as a propulsion system and considering frequency and amplitude of pitch and heave as a parameter of sinusoidal motion a hydrodynamic oscillating propulsion is represented. Flexibility part made by polydiethylsiloxane(PDMS). Sinusoidal motion created by two parker HV23 stepper motor. 16 bit digital data acquisition board table was used with 3 axis load cell to measure force and frequency with LabView code. MatLab also help in the recording of data. Flow pattern observed by particle image velocimetry and from experimental result it is seen that thrust co-efficient increase proportionally with chord wise flexibility. A. Mazumder and H.H Asada [11] investigated on a spheroidal Appendage-free under water vehicle to investigate the nuclear reactor inspection and other purpose. Mainly they focused on compact, multi DOF propulsion system and a high stable control system. For that a non linear hydrodynamic model is generated and analysed its controllability and stability by the application of water jet with Coanda effect valve and unique bidirectional centrifugal pump which generate four directional flows. Based on the analysis information a robot prototype designed which used to developed PD controller. T. I. Fossen and M. Blanke [12] suggest a non linear output feedback controller for UUV propeller. This is done from the feedback of estimated axial flow velocity. Using single propeller the simulation explain more accurate result. Lyapunov stability theory applied here. Assuming propeller revolution and axial flow velocity have the same signs two theorem of global exponential stable (GES) established. Disturbance created on thrust and torque by axial flow velocity compensate by estimated result which is so important from various point of view. C. Y. Hsu et al. [13] studied the stress concentration effect due to the penetrations in the pressure hull of a deep diving submersibles and its structural design. For that author investigate on shallow cylindrical shell by Hibbitt and Karlsson's methodology of FEM and analyse the curvature effect and failure modes on spherical deep diving vehicle under external pressure. Stress distribution at different curved angle of a circular hole helps to develop a design a data. For the study of elastro-plastic behaviour of material Von Mise's Yield criteria are used. Meshing is done by 9 nodes doubly curved thin shell element and considers 5 DOF. M. A. MacIver et al. [14] design underwater vehicle based on weakly electric fish sensory system, propulsion scheme and body design principle. Here they utilize an idealized ellipsoidal body model, Kirchhoff's equation and optimal control algorithm for generating trajectories. By applying artificial electro sensory around the AUV an Omnidirectional sensing volume created. T. F. Miller et al. [15] given a concept of morphing hull for underwater vehicle and discussed about its benefits specially range, endurance and speed. This is done by creating annulus for keeping the expandable energy between the pressure hull and flexible hull. Keeping the flexible hull shape same and varying the outer hull diameter morphing provides the benefits of decreasing the drag profile and increasing the vehicle range and change the effectiveness. As a result power consumption also reduces. Morphing is done by sliding the truss along the axial direction in the inner pressure hull and thus increases the height of the truss and decrease the outer hull diameter. A mathematical model developed using MatLab and based on the desired fuel for UUV carrying, vehicle configuration calculated. S. Kowalczyk and J. Felicjancik [16] had done investigation for the noise generation numerically and experimentally of a propeller. Under different loading condition the hydro acoustic behaviour are observed and compare with experimental results. From the result it was observed that the sheet cavitations start from 0.7-0.9R and blade angle -10º and got similar the hydro acoustic curve in both cases. L. X. Hou et al.[17] designed a marine propeller with Wake-adapted fixed guide vane that save energy. This proposal was made on propeller vortex theory (PVT) and surface panel method (SPM). The hydrodynamic interaction between the propeller and the FGV hydro dynamically is main part of the design of the propeller. From this design thrust increase by 8.7% and 8.3% propulsive efficiency instead of single propeller. T. Pechan and A. Sescu [18] studied experimental study about the noise emitted by propeller's surface imperfections in various field. Considering various imperfection of the propeller blade various type acoustic experiments have done under various conditions. From their experiment it was observed that surface imperfection does not create any great effect on acoustic property. And attaching a lot microphone at various points a lot of future work can be done. T. M. Hearth et al. [19] studied on composite marine propellers for isogeometric analysis and genetic algorithm study for shape-adaptive. Considering hydrothermal effects, using Non-Uniform Rational B-Splines (NURBS) based FEM coupled with real-coded Genetic Algorithm (GA) developed. Under different condition numerical tool used to optimize the frame work in this paper. Their observation shows 4% performance improvement. S. Mirjalili et al.[20] had done Optimisation of Marine Propellers from Multi-objective view. Here various experiment carried out considering various factor of structural parameters and operational condition. The main objective is to optimize cavitations and maximize efficiency. From their result, both optimizations achieved in case of 5 or 6 blade propeller and at a rotational speed of 170-180 RPM. S. Gaggero et al. [21] Design through the application of BEM and optimization algorithms of a contracted and tip loaded propellers. The design approach is based on a parametric description of the propeller blade, derived from the usual design table by using B-Spline parametric curves, and an in-house developed Panel Method/Boundary Element Method (BEM) aimed to evaluate the performance (including citations) of the propellers selected by a genetic optimization algorithm. The result obtained from their result was validated with experimental work. M.M. Bleiziffer et al. [22] developed a novel design method by computing the exact lift of arbitrary hydrofoils in cascades for a marine propeller for the recent application. Here several propeller designs simulated by RANS CFD. Through panel method two dimensional thin hydrofoils developed for computing flow field around it. In the present study was demonstrated how propeller performances were improved by making correct assumptions regarding the flow around the blade sections. A. Bhattacharyya et al. [23] investigated on a duct propeller for observing scale effect for a controllable pitch propeller with in different design duct. this is done through use of three different duct and solving CFD simulation .They concluded that propeller torque decreases 3-4% in case of full scale from model scale. The performance of various duct propeller are compared based on merit co-efficient. X.Weng et al.[24]experimented on an underwater structure and observe its acoustic response due to mechanical excitation. For that they consider a cylindrical shell with internal bulkhead which is made of FGM core with absorbing material coating. Boundary element method and Helmholtz integral formulation used for acoustic analysis. The shell is closed with truncated conical shell which also closed by circular bulkhead. Inside part of the shell had made by metallic material. The model is structure similar to submarine hull. Due to conical shape basic non linear geometric equation established. The motion equations are transformed to displacement equation and applied boundary condition. From the material property and structure analysis it has been observed that stiffness change with the change of volume fraction exponent and with the increase of dynamic response mechanical force. N. A.Hussain et al. [25] investigated on under water glider modelling for analysis of net buoyancy, depth and pitch angle control. For that they chose a ballast tank sub system considering ballast rate is the main input and find the three outputs. This is done by MatLab system identification tool box TM. The simulation and output results are compared and based on the obtained information USM underwater glider prototype control system designed and optimized. Besides that stabilization and robust analysis of the glider also done. H.M.T Khalled et al. [26] discussed about the optimization process and thermal analysis of propeller hub of AUV for flash less cold forging and simulated through FEM. Considering Al as a model material deformation analysed by rigid plastic finite element method , where the material follow the von misses yield criteria as assumption. Here through the SOLID WORKS SP472007 software model develop and in the STL format simulated in DEFORM-F3 3D software. The main focus of the paper is to remove the flash, which is done by repeating the simulation considering hexahedron as a meshing element. Here optimization is confirmed through temperature distribution technique and observing thermal analysis. 100 ton C- type forging machine used for experiment purpose and compared with simulated result. L. Moreira and C. G. Soares, [27] described two control system by applying two separate method (H_2 and H_α method).this is done for controlling its course and lateral position. Result of both models compared and analysed with in its own domain for disturbance rejection and to observe sensitivity of sensor noise. Z. Zhenqian et al. [28] had studied the failure analysis of blade fastening bolts of a marine propeller under various stress condition. Here hydrogen concentration gradient helps to drive hydrogen diffusion and through experiment and FEM analysis stress concentration also measured. From the FEM analysis maximum stress generated 1016 MPa from where crack generation started on roof surface of the bolt. G. Dubbioso et al. [29] Analysis a marine propeller performance operating in oblique flow through the numerical solution of

Reynolds averaged Navier–Stokes equations. Considering two separate loading conditions and different incidence angles (10–30°) analysis carried out and corresponding characteristics of the propeller performance during idealized off-design conditions are observed. Results show that in a common off-design scenario of ship operation (i.e. manoeuvring), thrust increase by 20% and torque 40% respectively. G. Ferri et al. [30] developed a small sized autonomous surface vehicle (ASV) for the observation of costal water quality specially hydrocarbon and metal concentration (heavy) through the custom mad miniaturized sensor. This device able to collect sample from 50 m depth and analysed the water later on. Due to intrinsic shape stability and low drafting catamaran solution are used for optimization. Carbon fibre used as a building material keeping on mind about the guarantee. Based on three layer structure HydronNet ASV navigation system developed. X. U. Feng et al. [31] discussed a parametric identification and sensibility analysis for AUV in diving plane. By applying simple calculation viscous hydrodynamic derivatives sensibility measured. This is done by LS-SVM method and thus forming mathematical model. Based on mathematical model a zigzag type simulation has done. By applying dominant sensitive and co-efficient the numerical simulation and sensibility analysis has done. Through co-ordinate system the motion characteristic of AUV described. In this study infinite deep and unbounded flow field is assumed and ignorance done in environmental disturbance. Forth order Runge-kutta method used in manoeuvring simulation. Based on the simulation result a model is reconstructed and compare with the previous model and also naturally apply for manoeuvring study. A Saeidinezhad et al. [32] investigated experimental work of non axisymmetric nose sub marine model to study its behaviour in pitch manoeuvre. This is done in a wind tunnel with Reynolds no 6.6 x 10^6 based on model length and pitch angle $-10^\circ \leq \alpha \leq 27^\circ$. The change in drag and lift co-efficient are observed with the change of pitch angle. At various pitch angle cross flow vortices and flow separation around the sub marine model are tested by smoke flow visualization test. Aluminium and wood are used to produce the model in CNC machine and aerodynamic force and moment are measured.

3. FUTURE SCOPE OF RESEARCH

Although all most all the research field related to propeller of underwater vehicle has done various authors, but a lots of research gap still there in which field next future work can be done. Very few authors' works on field about the material study of propeller, structural analysis, failure criteria, power generation. Besides that use of non convention energy source to produce propulsive thrust on the propeller may be a big field for the next future work. Since marine device become a important part military department, so some research work can also done in propeller acoustic property, hydrodynamic field so that our enemy cannot easy harm. Thermal heat generation and its effect get very less attention in research work of propeller by various authors.

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