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INFLUENCE OF INCREASING NUMBER OF BLADES ON THE INTERNAL STRUCTURE OF HYDRO PROPELLER

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ABSTRACT

Ships and underwater vehicles such as submarines and torpedoes use hydro-propellers to generate propulsive force in order to move in water, hydro-propeller is a component used to convert the rotational motion to thrust, as a result of pressure difference between face side and back side of blade surface. According to this effect the water will accelerate behind the propeller blades, the pressure difference acts the internal structure of propeller and this will produce a deformation effect on propeller blades and also Intensification of the dynamic and static stresses. All of these will negatively affect the hydrodynamic performance of the propeller. The aim of this research is to investigate numerically, by using ANSYS-Structural 16.1 software, the effect of increasing blades number on the propeller structure and to study the interaction between these stresses on propeller performance. The results showed that the number of propeller blades negatively affect internal structure of propeller. The mechanical stresses like Von-Mises stress, Equivalent elastic strain and deformation will increase as the propeller blades number increases to record maximum value in propeller with five blades. Furthermore the mechanical stresses concentrated in blades roots region where the blades are fixed in propeller hub.

Keyword head: Propeller structural analysis, Propeller blade deformation, Numerical study, CFD analysis, Mechanical performance of hydro-propeller**.**

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1. INTRODUCTION

Hydro-propeller is the main component of driven force in underwater vehicles, due to the effect of hydrodynamic pressure difference between face and back surfaces of blade. As a result, internal structure of propeller will be subjected to high stresses on its internal structure, so it's important to study and analyzes all the external influence on propeller blades. Due to the complicated propeller blade geometry: it's necessary to use a helpful numerical tool to analyze such effects. Static analysis was done by Barru Harish et al,[1] they studied and analyzed effect of stresses on marine propeller for four models, each model differs from other in manufacturing material, they used aluminum ,R-glass,S2-glass and carbon fiber reinforced plastics. Prop-Cad and CATIA software was used to build up the geometry then simulated it by FLUENT 6.3.26, the results showed that high stress caused less deformation in propeller with aluminum material than R-glass epoxy material. An analyzing study was carried out by P. DurgaNeeharika and P. Suresh Babu [2] to investigate the static analysis of aluminum propeller blade of underwater vehicle; Due to complex geometry of propeller they used CATIA-V5 R20 software to generate the solid model and HYPER mesh to create tetrahedral mesh. They treat propeller blade as cantilever beam fixed from side and free from other side, the results showed the maximum deflection of propeller blade was 6.88 mm and the maximum value of von mises-stress was 525.91 N / m2, high stresses are concentrating in the intersection part of blade-hub region and decrease gradually toward blade tip and edges. A static structural analysis was done by PALLE PRASAD and LANKA BOSU BABU[3] to investigate of structural analysis for two materials, graphite fiber reinforced plastic (GFRP) and carbon fiber reinforced plastic (CFRP),due to complicated geometry form of three dimension propeller CATIA software was used to generate the model, the results of numerical simulation was carried out by using ANSYS software. The results showed that Von Mises stress was reduced to 31.4% when propeller blade material changed from CFRP to GFRP. Static and dynamic analysis for aluminum and Carbon UD/Epoxy materials to predict the safety factor and avoid fatigue problems was carried out by R. Surendra Rao et al,[4] they use CATIA software to generate complex propeller blade model and HYPERMESH to develop fine mesh for accurate results, the numerical result was done using ABAQUS software based on Finite element method, the results found the carbon UD/epoxy material can improve propeller performance and give high fatigue life. M.L.Pavan Kishore et al,[5] studied and analyzed effect of static and dynamic stress for two types of propeller Nickel Aluminum Bronze (NBA) propeller and composite material propeller using high end modeling software/CATIA V5 R17 and HYPER MESH to generate Hexa-solid mesh for more accurate results, the results was carried out using ANSYS software, they found propeller blade with composite material has deflection equal to 0.897 mm, while the deflection magnitude for NAB propeller was 0.597 mm and the natural frequency of composite material propeller due to Eigen analysis was 22% more than NAB propeller. Hydro-elastic analysis was carried out by Morteza GHASSABZADEH et al, [6] to investigate the effect of deformations result of skew angles on the propeller performance of copper high tensile brass propeller model, they used numerical analysis based on A coupled boundary element method (BEM) and finite element method (FEM), the results showed the propeller efficiency improve with increasing advance velocity and blade skew angle, and the propeller with brass material has less deformation as compared with composite one. static and dynamic analysis were performed by S. Abdul Mutalib et al,[7] to investigate the strength and deformation of marine propeller for three types of fabrication material like aluminum, carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP), Solidwork program was used to generate solid model, the numerical simulation was done by ANSYS software due to complicated geometry of solid model, the results showed glass fiber reinforced material (GFRP) is suitable fabrication material and can improve propeller performance. Design and optimization study was done by Jose ´ Pedro Blasques et al,[8] to investigate the effect of configuration of laminate lay-up and blade pitch angles of composite propeller blade with controllable pitch and high skew for two various load conditions maximum and cruising speed, the used Tsai-Wu strength index to analyze blade strength, the results found the maximum failure index of Tsai-Wu was decreased from 1.6 to 0.7, from that they suggest no failure occurs. A numerical study based on L8 orthogonal array was done by S.Solomon Raj and Dr.P.Ravinder Reddy[9] they investigate the behavior of composite material propeller under hydro dynamic loading, the results found arrays of Taghchis orthogonal can be used effectively to understanding the influence of various parameters and its effect will reflected on propeller performance. The present work aims to investigate the effect of increasing blades number on the internal structure of hydro-propeller using ANSYS software to analyze the stresses and deformation of propeller blades for three models that designed and created by using SOLIDWORK program**.**

2. GEOMETRY OF PROPELLER

Propeller is a significant part in water an underwater vehicles, because the propeller gives vehicle the forward motion and accelerate it from static position due to the pressure difference between the front side and back side of propeller blades, tables 1 and 2 illustrate the geometric and mechanical properties were adopted in this study.

Table 1 Geometric properties of ship propeller

No.	Geometric properties	Magnitude	Unit
1	Diameter	0.6	m
2	Hub diameter	0.08	m
3	Number of blades	3,4,5	--
4	Pitch to diameter ratio	1.2	--
5	Rotational speed	17.17	Rev/sec
6	Advance speed	9	m/sec
7	Advance coefficient (j)	0.88	--
8	Expanded area ratio	1	-
9	Skew (degree)	0	degree
10	Rake (degree)	0	degree

Table 2 Aluminum mechanical properties

No.	mechanical properties	magnitude	unit
1	Young's Modulus	7000	MPa
2	Poisson ratio	0.34	-----
3	Mass density	2700	gm/cc
4	Damping coefficient	0.03	----

3. COMPUTATIONAL DOMAIN

To study the propeller performance in open water conditions two domains must be created; rotating domain and stationary domain. The rotating domain represents the propeller model, while the stationary one represents the environmental flow around the propeller. The water was selected as a working fluid, as shown in Figure 1.

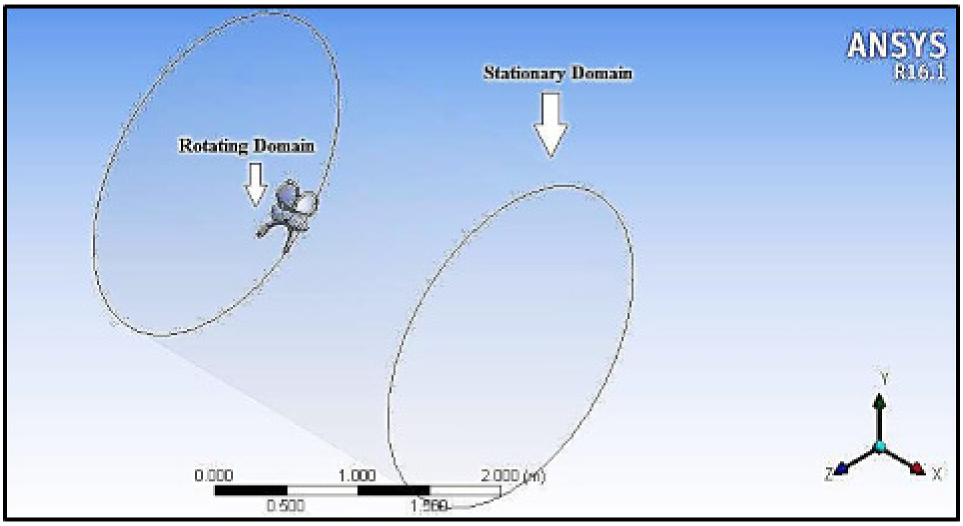

Figure 1 Propeller Computational Domain

3.1 Modeling geometry

Solid work software was adopted in this study to design and create the stationary and rotating domains as illustrated in Figure 1. Three models of rotating domain has been designed and created, each one differs from the others in blades number. All cases were designed with respect to maintain blade surface area constant when the number of propeller blades increases. As shown in Figure 2.

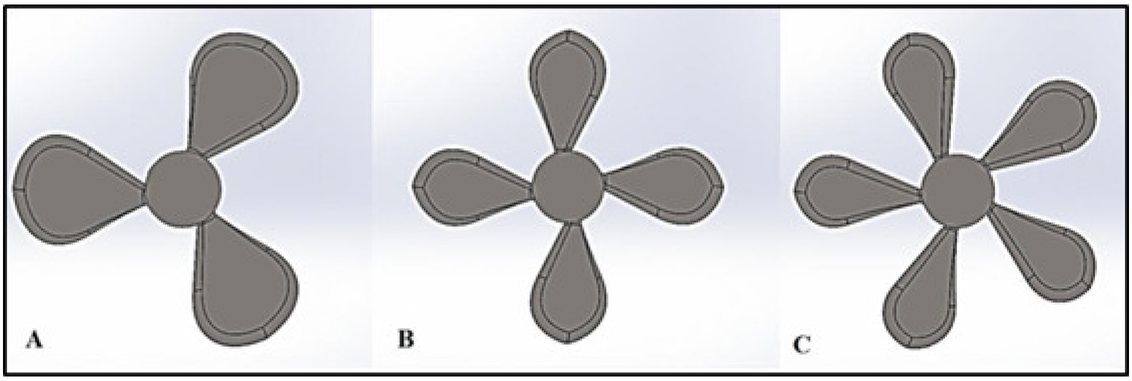

Figure 2 Front view of Propeller: A-3blades, B-4 blades, C-5 blades

3.2 Mesh generation

Due to complicated geometry of propeller blade, unstructured mesh type has been selected in this work as shown in Figure 3. This type of mesh is suitable and gives better results. Refine mesh technique was adopted in the regions where blades intersect with propeller hub and also in the region near blades tips because the regions are constantly exposed to highly stresses, to check the effect of grid resolution on accuracy of numerical results. Three types of mesh were applied; coarse, medium and fine, as illustrated in Table 3. Von-Mises stress was selected as a grid resolution criterion to show which of these three types gives best results. As shown in Table 3, the error percentage of the last two cases was 2.1 %, which is too small as compared with number of element and this will increase running time with no benefits, so the second type of grid resolution "medium size" was adopted in all cases, as shown in Figure 3.

Table 3 Grid resolutions

No.	Mesh type	Number of elements	Von-mises stress
1	Coarse	883,943	0.00815 MPa
2	medium	1,950,838	0.00786 MPa
3	fine	2,642,315	0.00769 MPa

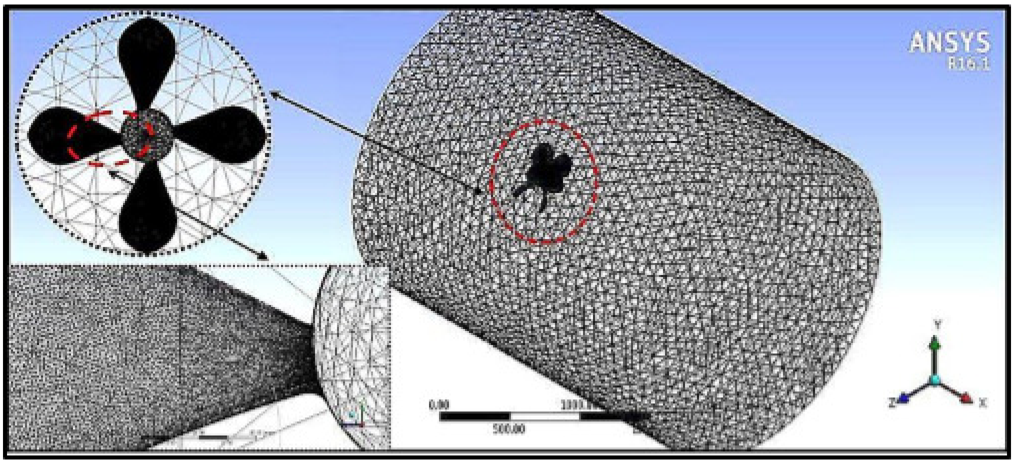

Figure 3 Meshing propeller domain with unstructured mesh.

3.3 Boundary conditions

The boundary conditions used to introduce flow variables on boundaries of physical model. In this study three types of boundaries were adopted, Flow velocity normal to the boundary in axial direction was selected as inlet boundary condition, while the flow exit from stationary domain was introduced as pressure outlet; the peripheral side of stationary domain has been specified as wall with no slip shear condition, as shown in Figure 4.

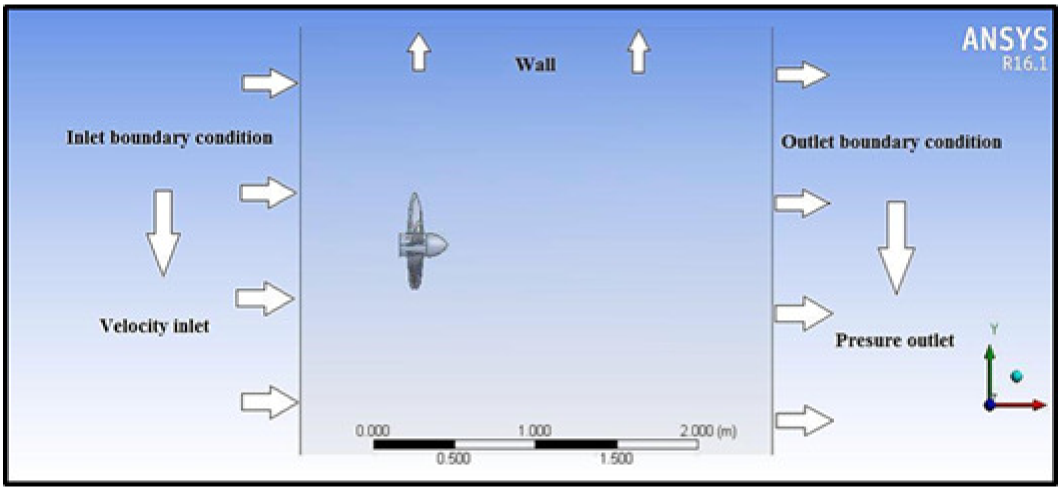

Figure 4 Specifying boundary conditions.

3.4 Numerical solution

ANSYS-Structure 16.1 software was adopted in this study to analyze mechanical stresses on propeller blades, the software procedure based on converting the governing equations to algebraic equations that can be solved numerically. The solution residual has been selected to 10^{-3} for all equations to maintain dwindling gradually from start to end of iteration. 800 iterations were adopted in this work to get better and more accurate results.

4. RESULTS AND DISCUSSION

The numerical analysis of aluminum propeller was carried out using finite element method; the numerical results of static and dynamic analysis were inserted in the form of graphs and figures.

4.1 Static analysis

Because of pressure difference between the front side and back side of blades thrust will be produced. The thrust force change with number of blades increase and this affect the internal structure of propeller. To analyze the numerical results the propeller blade treated as cantilever beam (one end is stationary “fixed in propeller hub “and the other end is free to move). Figure 5 shows contours of Von-mises stress for three types of propellers. Von-mises stress concentrates in the intersection region of root-hub. Von-mises stress increase as the propeller blade number increases to record 0.01063 Mpa in propeller with five blades as shown in Figure 8.

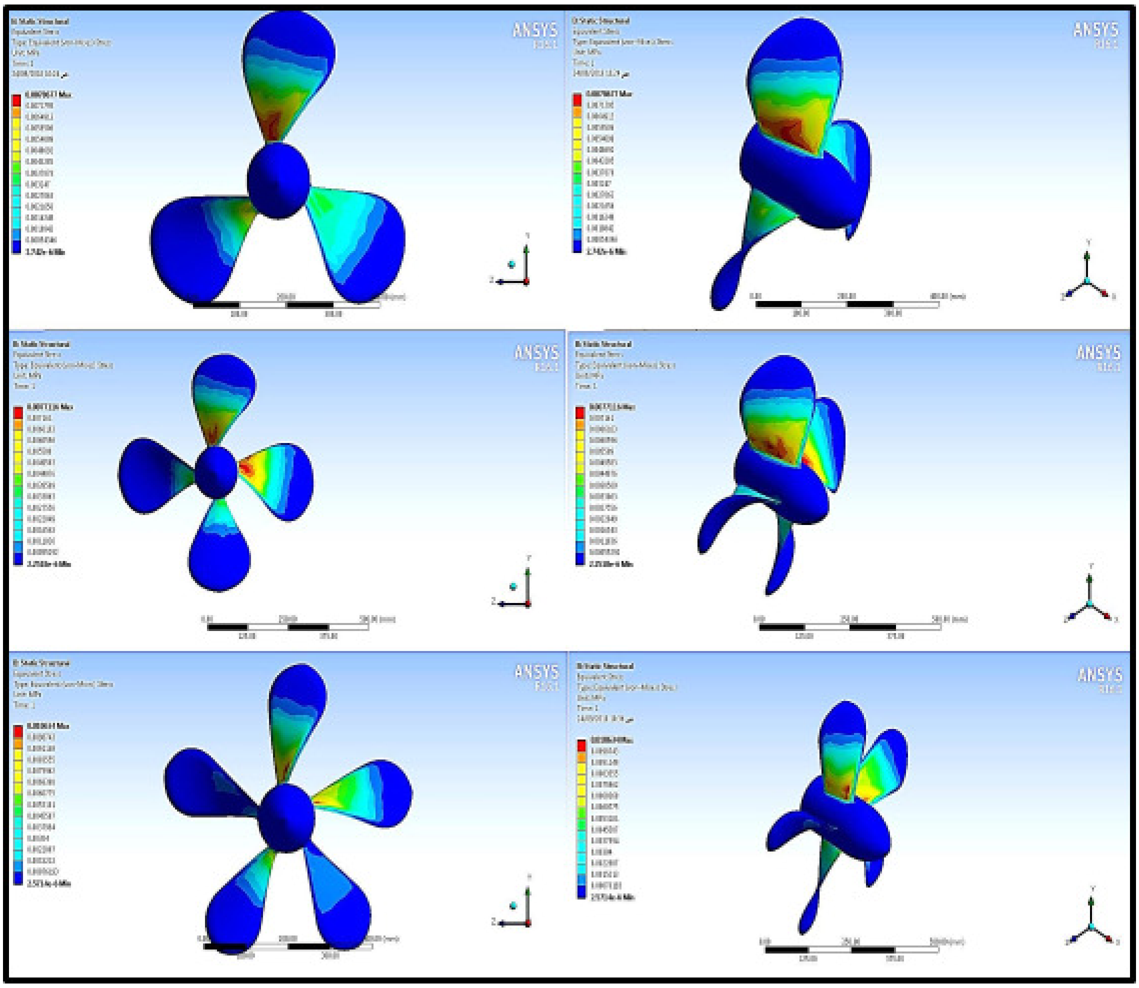

Figure 5 Von-Mises stress contours for three types of propellers

Figure 6 shows contours of Equivalent elastic strain for three types of propeller, Equivalent elastic strain concentrate in the intersection region of blade root-hub. Equivalent elastic strain increase as the propeller blade number increases to record 1.5×10-07 in propeller with five blades as shown in Figure 9.

Figure 7 shows contours of Deformation for three types of propeller, the deformation of blades concentrates in blade’s tip and decreased gradually toward blade root. Deformation increase as the propeller blade number increases to record 0.00058 mm in propeller with five blades as shown in Figure 10.

Finally As seen from Figures 8 and 10, the results of four bladed propeller shows low values of both Von-misses stress and deformation as compared with the other cases. This is mainly due to reducing in blade thickness that calculated from blade root to the tip, where the change in thickness of the four bladed propeller recorded as 0.92 mm compared to 0.95mm and 1mm for three and five bladed propellers respectively, as shown in Figure 11.

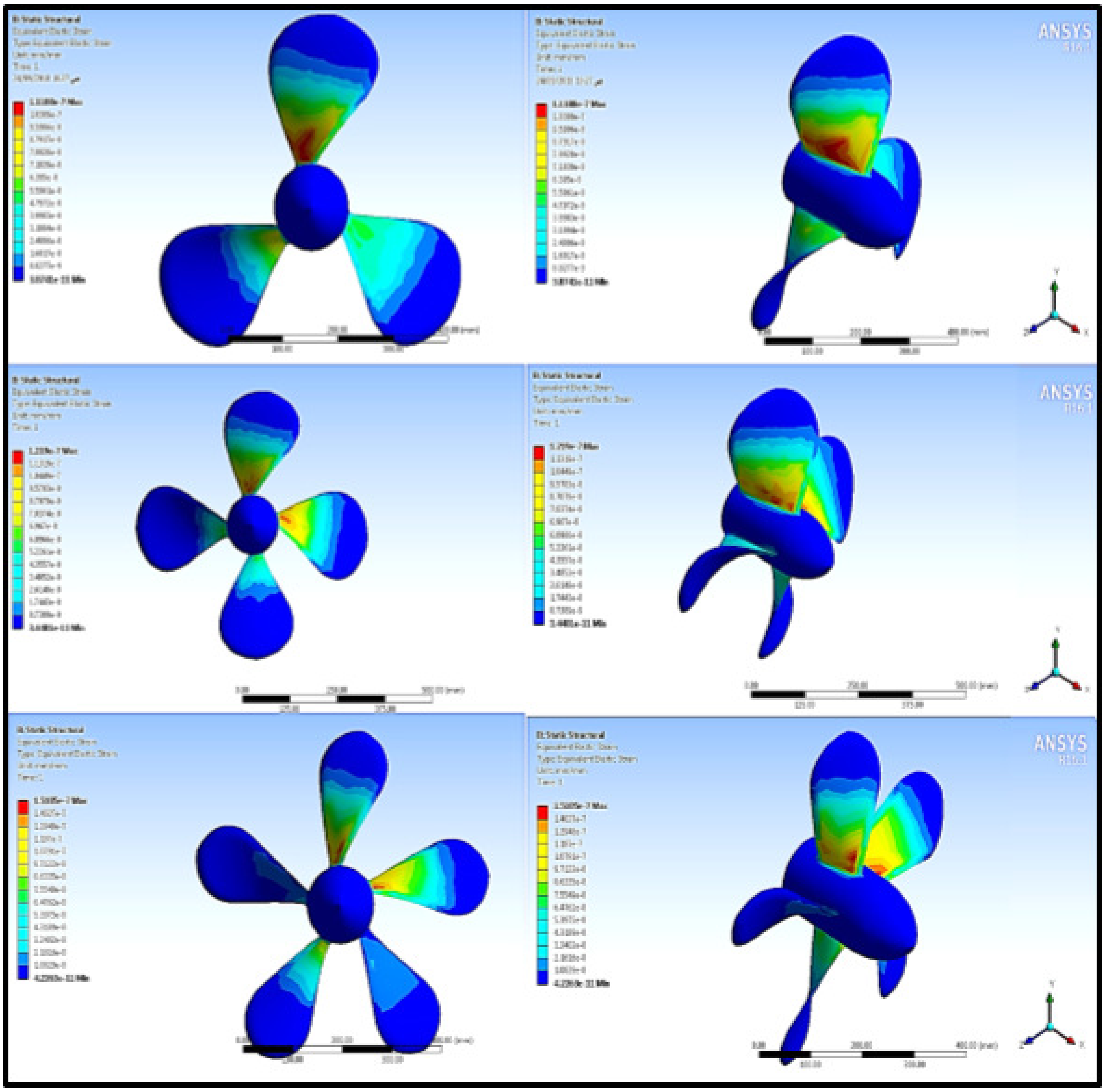

Figure 6. Equivalent elastic strain contours for three types of propellers

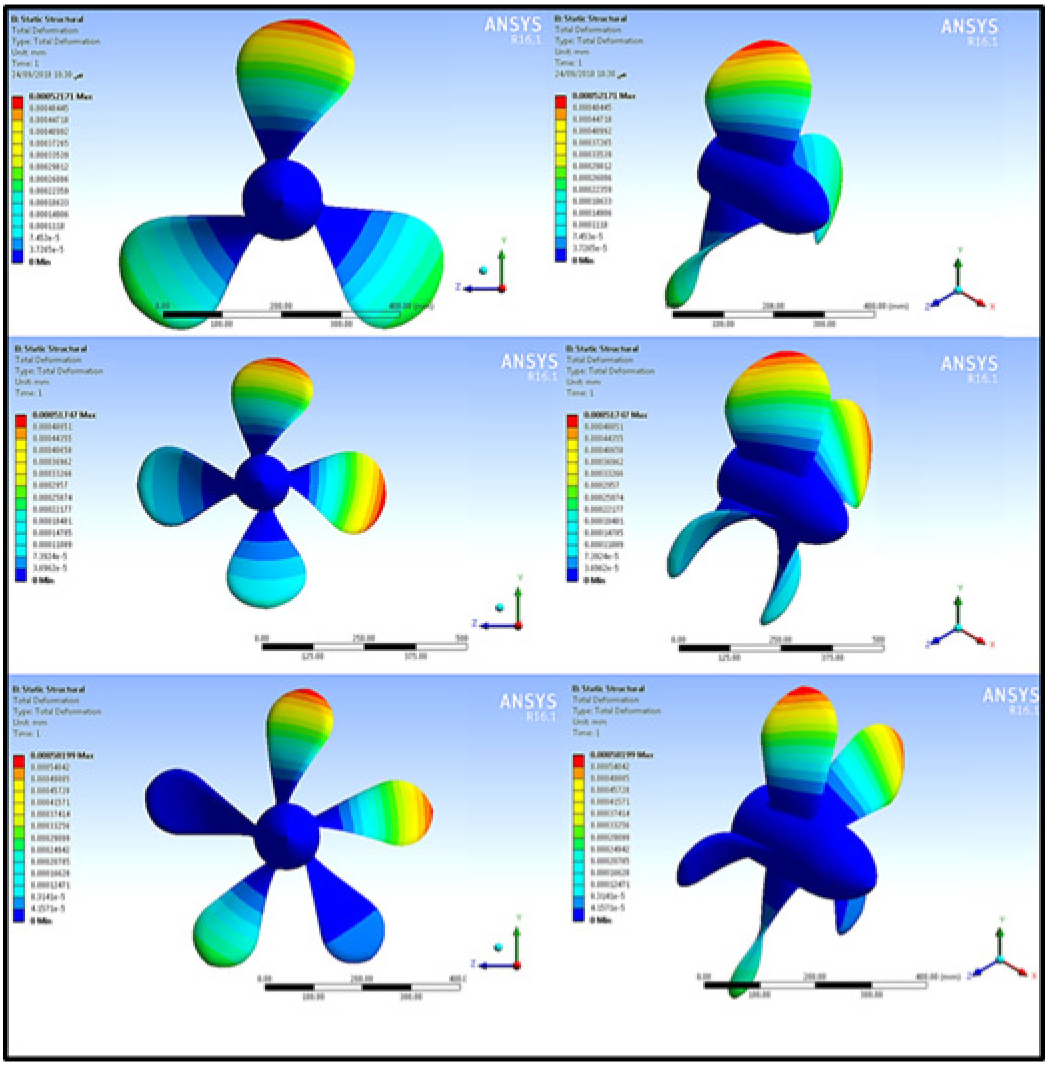

Figure 7. Deformation contours for three types of propellers

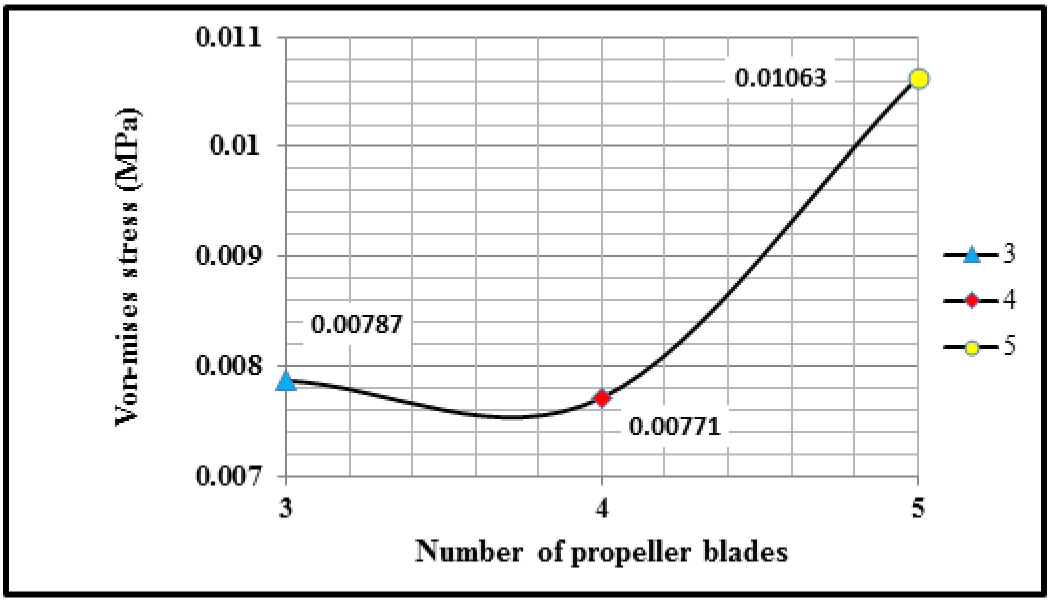

Figure 8 Von-Mises stress for three types of propellers

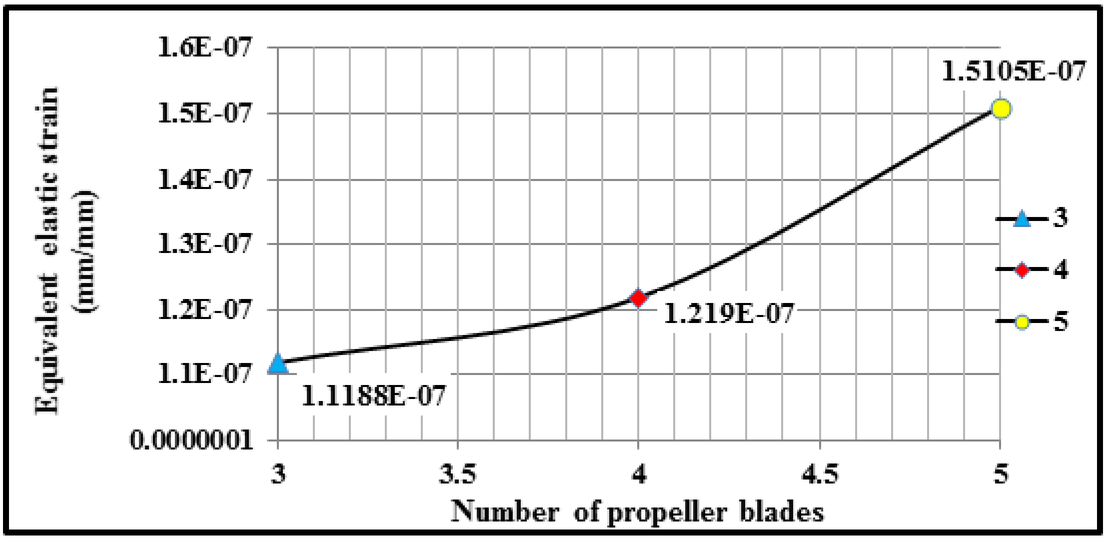

Figure 9 Equivalent elastic strain for three types of propellers

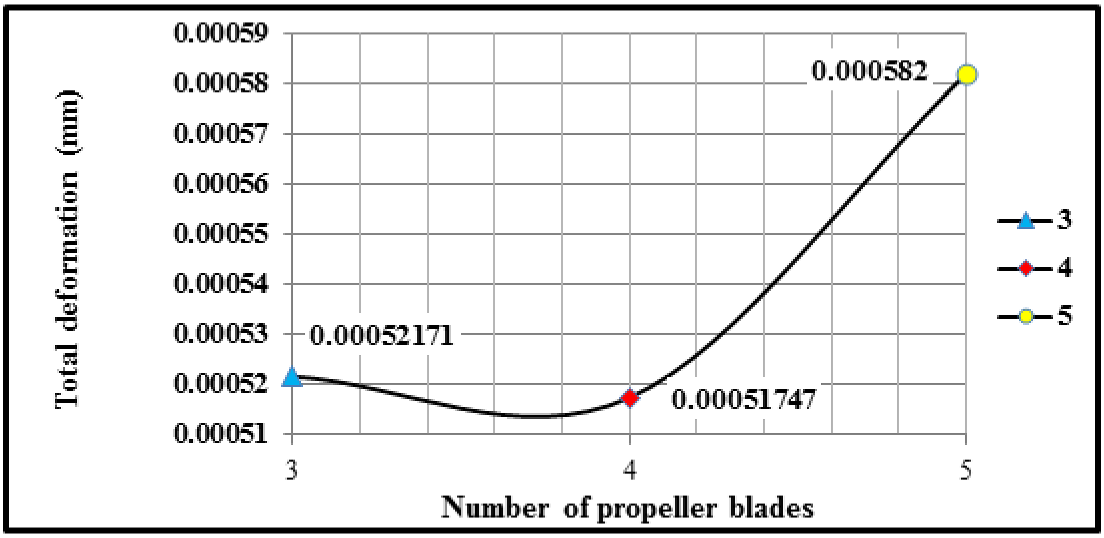

Figure 10 Deformation for three types of propellers

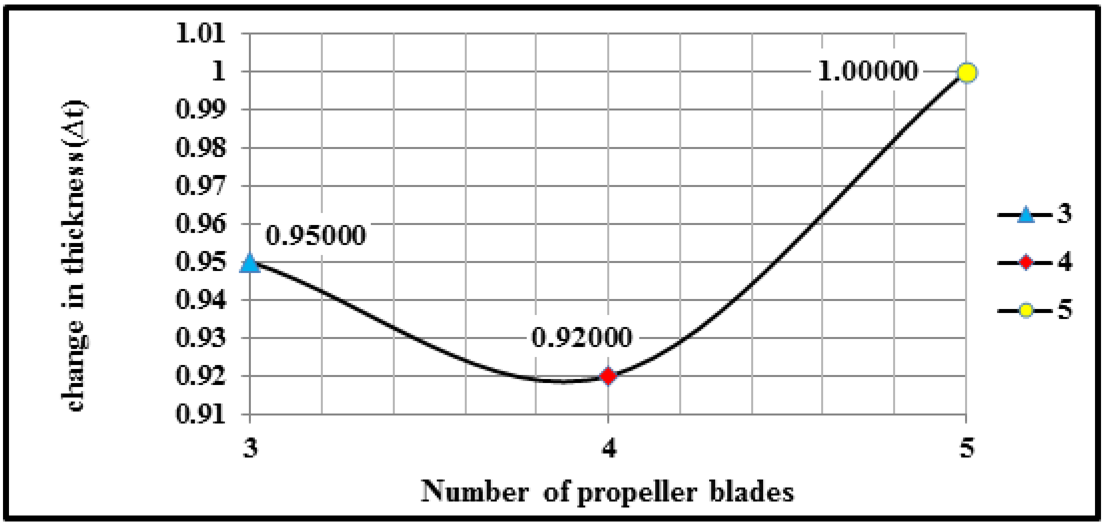

Figure 11 Change in thickness for three types of propellers

5. CONCLUSIONS

A numerical analysis was carried out using ANSYS-CFX to study and analyze effect of increasing propeller blades number on the internal structure of hydro-propeller, three types of hydro-propeller was designed and modeled using SOLIDWORK program. The design operation included increasing of propeller blades based on maintaining blade surface area of propeller constant. The numerical results show the following points:-

1. High stresses are concentrating in the intersection part of blade-hub region and decreased toward blade tip.
2. Von-Mises stress increase as blade number increases to record 0.01063 Mpa in propeller with five blades.
3. Equivalent elastic strain increase as blade number increases to record $1.5 *10^{-7}$ in propeller with five blades.
4. Maximum deformation appear in blades tips due to maximum pressure applied on blades leading edges
5. Deformation increase as blade number increases to record 0.00058 mm in propeller with five blades.
6. Four bladed propeller shows low values of both Von-misses stress and deformation as compared with the other cases, because of it has minimum value of change in blade thickness calculated from blade root to the tip.

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