Improving Efficiency Of Submersible Pump Impeller By Design Modification Through Cfd And Structural Analysis

S Sivaanjaneyulu[#1], Dr.K. Lalitnarayan[*2], E. Venkateswararao[#3] M.N.V.Alekhya[*4]

[#]*IV Sem M.Tech in Machine Design & Mechanical Engineering& Sir C.R.Reddy College of Engineering, Eluru.-534007*

[#] *Professor & Mechanical Engineering & Sir C.R.Reddy College of Engineering, Eluru.-534007*

[#]*Assistant Professor & Mechanical Engineering& Sir C.R.Reddy College of Engineering, Eluru.-534007*

[#]*Assistant Professor & Mechanical Engineering& Sir C.R.Reddy College of Engineering, Eluru.-534007*

ABSTRACT

The main aim of this thesis is to increase the efficiency of the pump impeller by modifying the existing design (i.e.) modifying exit blade angle and width of the impeller. Theoretical calculations will be done to determine the efficiencies for existing and modified designs. 3D models of the pump impeller will be done in CREO. CFD analysis will be done in order to determine the pressures, outlet velocities, mass flow rates. Structural analysis will be done by applying pressures obtained from CFD analysis by changing the materials of the impeller. The materials considered will be Steel, Aluminum alloy and Titanium alloy. Analysis will be done in ANSYS.

INTRODUCTION

There are two ways of optimizing the pump performance, first by optimizing the cost and the second by increasing the overall efficiency of the pump.

The second way, i.e. increasing the overall efficiency of the pump, involves improving quality, analysis and design; hence this method of optimizing is opted. The pump model G554T, which is a de-watering, semi-open and mixed flow type of submersible pump, is the fastest moving submersible pump manufactured by Mody Pumps (India) Pvt. Ltd. So this project work is conducted on the model G554T. Even a small increase, say by 1%, in the overall efficiency of the pump yields a lot of profit for the firm.

The main aim of the project is to study and analyze the existing pump model G554T and to re-design the model G554T so that its pump efficiency can be increased, thus increasing its overall efficiency.

The overall efficiency constitutes of Motor efficiency and Pump efficiency. The motor efficiency is related to the stator winding and the number of poles it is having. The pump efficiency is given by the product of Mechanical, Disc friction, Volumetric and Hydraulic efficiency [1]. The existing motor of G554T is providing an efficiency of 88.2% at 100% load [2]. Thus there is hardly any necessity of improving its efficiency. Hence the concentration is done on improving the pump efficiency, which thereby increases the overall efficiency.

A wide variety of centrifugal pump types have been constructed and used in many different applications in industry and other technical sectors. However, their design and performance prediction process is still a difficult task, mainly due to the great number of free geometric parameters, the effect of which cannot be directly evaluated. The significant cost and time of the trial-and-error process by constructing and testing physical prototypes reduces the profit margins of the pump manufacturers. For this reason CFD analysis is currently being used in the design and construction stage of various pump types. From the CFD analysis software and advanced post processing tools the complex flow inside the impeller can be analyzed. Moreover design modification can be done easily and thus CFD analysis reduces the product development time and cost. The complex flow pattern inside the centrifugal pump is strong three dimensional with recirculation flows at inlet and exit, flow separation, cavitation. Also the efficiency of the impeller can be improved by changing the volute design of the impeller and by increasing the number of impeller blades.

SUBMERSIBLE PUMP IMPELLER DESIGN CALCULATIONS

Eye Diameter of Impeller D_e = 36mm = 0.036 m

Inlet diameter of impeller d_i = 60mm = 0.06m

Outlet diameter of impeller d_o = 195mm = 0.195m

Blade width at inlet = B_i (m)

Blade width at outlet = B_o (m)

Thickness of blade t = 7.36mm = 7.36×10^{-3} m

Blade inlet angle = β_i

Blade outlet angle = β_o

Head developed = H (m)

Inlet Height of Blade = hi = 64 mm = 0.064 m

Outlet height of Blade = ho = 53 mm = 0.053 m

Inlet Width of Blade Angle $= \alpha i = 30^0$

Out let Width of Blade Angle $= \alpha i = 40^0$

Discharge $= Q\ [\frac{m^3}{sec}]$

Gravity $= g = 9.81\ \frac{m}{sec^2}$

$C_v = 0.98$

Speed of the impeller $= \eta_s = 2800$ rpm

Power = 3HP

Number of blades Z = 3, 4, 5

NO OF BLADES - 3
BLADE ANGLE – 40⁰

Inlet Area $A_i = \frac{\pi}{4} d_i^{\,2}$

$$B_i = \frac{A_i}{\pi d_i \frac{Z \times t}{\sin \beta_i}}$$

Head H is calculated

$$H = 2.79 \times 10^{-4} \times \eta_s^{\,2} [d_o^2 - d_i d_o \times \frac{\tan \beta_i}{\tan \beta_o}]$$

Inlet velocity is $V_i = C_v \times \sqrt{2 \times g \times H}$

Discharge Q is Calculated

$$Q = 0.1644 \times d_i^{\,2} \times B_i \times \eta_s \times \tan \beta_i$$

MODELING OF SUBMERSIBLE PUMP IMPELLER

BASED ON ABOVE CALCULATIONS

NO OF BLADES - 3
BLADE ANGLE - 40⁰

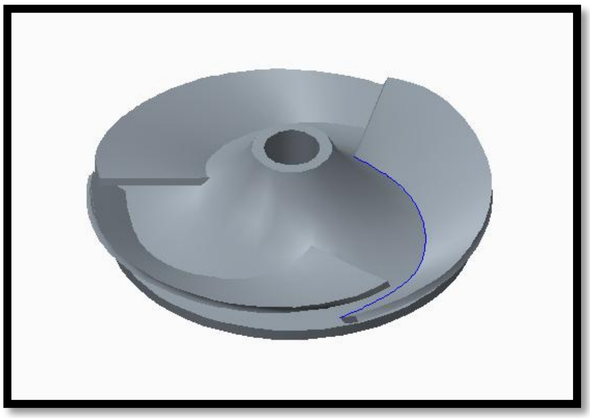

Fig.1 – Final 40^0 angle model

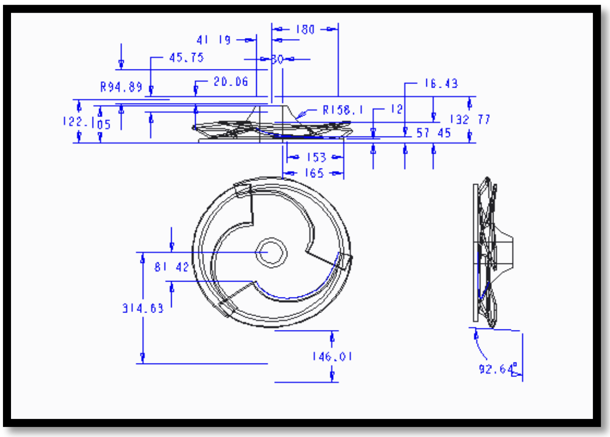

Fig.2 – 2D Drafting of 40^0 Angle

ANALYSIS OF SUBMERSIBLE PUMP IMPELLER

BOUNDARY CONDITIONS

The submersible pump impeller is analyzed in CFD by applying the velocities are taken from the above calculations and the structural analysis is done by applying the internal pressure values obtained from CFD analysis.

CFD ANALYSIS OF SUBMERSIBLE PUMP IMPELLER

FLUID – WATER

NO OF BLADES - 3
BLADE ANGLE – 40⁰

Boundary conditions → select air inlet → Edit → Enter Inlet Velocity → 38.162m/s and Inlet Pressure–1013250Pa

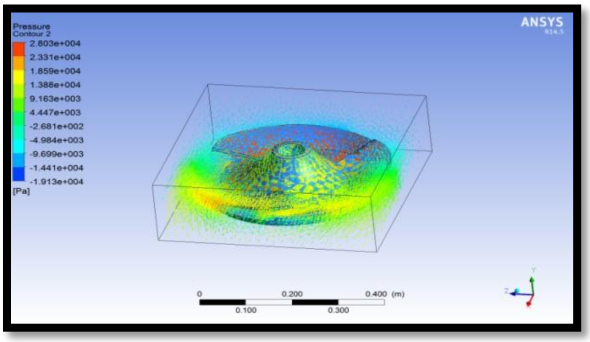

Fig.3 – Static pressure contours
Maximum pressure is obtained at outlet of pump 2.803e+4 and minimum pressure is 4.43e+4

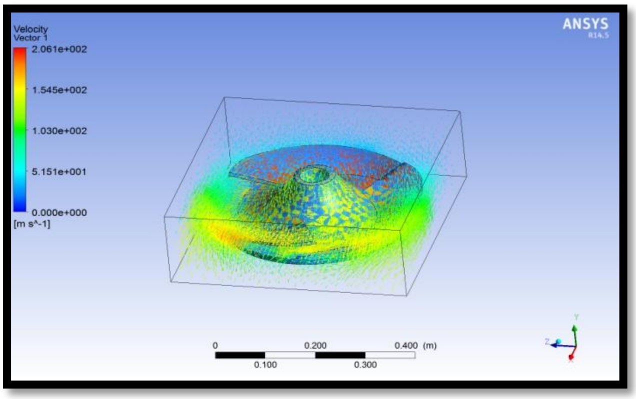

Fig.4 – Velocity magnitude
Maximum velocity is obtained at outlet of pump 2.061e+2 m/sec and minimum velocity is 5.151e+1 m/sec at walls of pump

MASS FLOW RATE

Table. 1: Mass flow rate

S.No.	Mass flow rate	Kg/s
1	Contact_region-src	0
2	Contact_region-src	0
3	In	11.201035
4	Interior-_____msbr	0
5	Interior-solid	-6.1488695
6	Out	-11.228067
7	Net	-0.027032852

CFD ANALYSIS RESULTS

NO OF BLADES – 3

Table. 2: CFD analysis result for 3 blades

BLADE ANGLE $(^0)$	**Pressure(Pa)**	**Velocity (m/s)**	**Mass flow rate (kg/s)**
40	$2.803e^{+004}$	$2.061e^{+002}$	-0.027032852
45	$2.804e^{+004}$	$1.876e^{+002}$	-0.029628754
50	$2.922e^{+004}$	$1.973e^{+002}$	-0.035345078

NO OF BLADES – 4

Table. 3: CFD analysis result for 4 blades

BLADE ANGLE $(^0)$	**Pressure(Pa)**	**Velocity (m/s)**	**Mass flow rate (kg/s)**
40	$2.603e^{+004}$	$1.939e^{+002}$	-0.007174491
45	$3.894e^{+004}$	$2.508e^{+002}$	-0.032691002
50	$3.014e^{+004}$	$2.063e^{+002}$	-0.029935837

NO OF BLADES – 5

Table. 4: CFD analysis result for 5 blades

BLADE ANGLE $(^0)$	**Pressure(Pa)**	**Velocity (m/s)**	**Mass flow rate (kg/s)**
40	$2.807e^{+004}$	$1.937e^{+002}$	-0.031002045
45	$2.912e^{+004}$	$2.030e^{+002}$	-0.041711807
50	$4.218e^{+004}$	$3.419e^{+002}$	-0.036879539

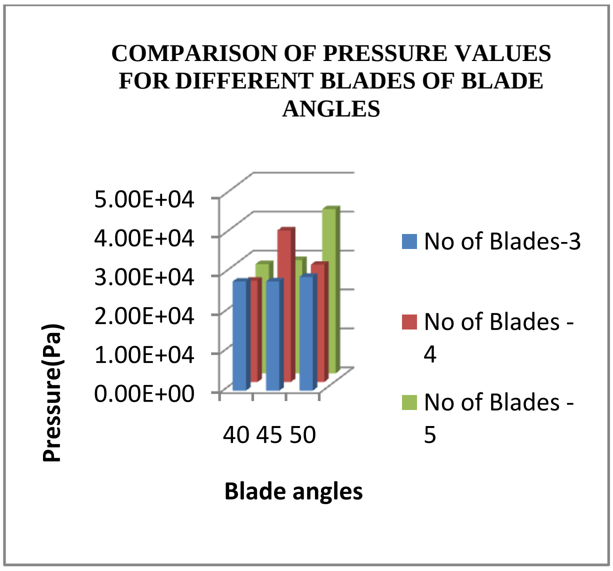

Fig.5 Maximum Pressure obtained at Blade angle 50 and having 5 Blades

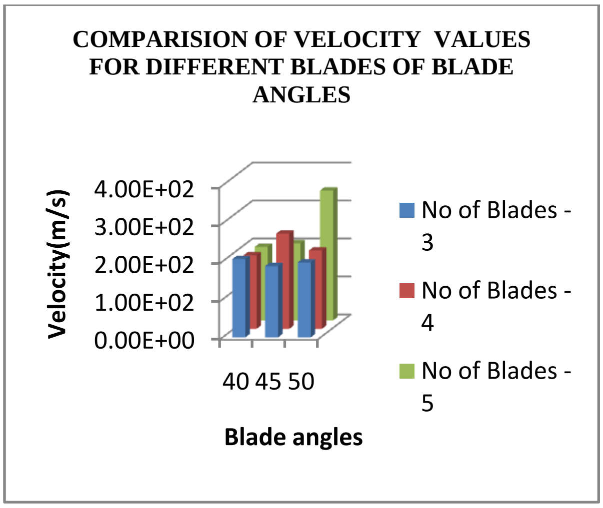

Fig.6 Maximum Velocity obtained at Blade angle 50 and having 5 Blades

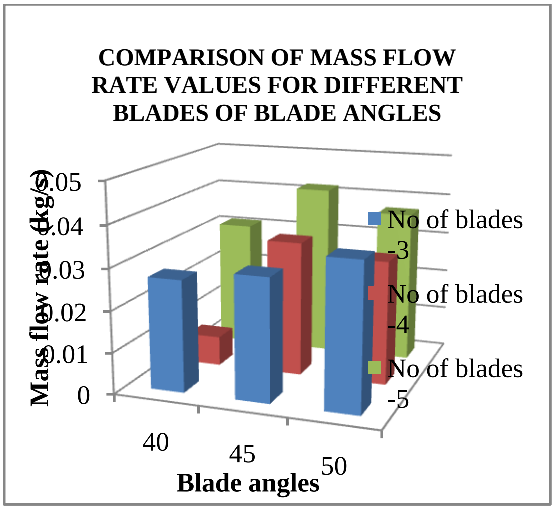

Fig.7 Maximum Mass flow rate obtained at Blade angle 45 and having 5 Blades

STRUCTURAL ANALYSIS OF SUBMERSIBLE PUMP IMPELLER
NO OF BLADES – 3

BLADE ANGLE – 40^0
MATERIAL – STEEL

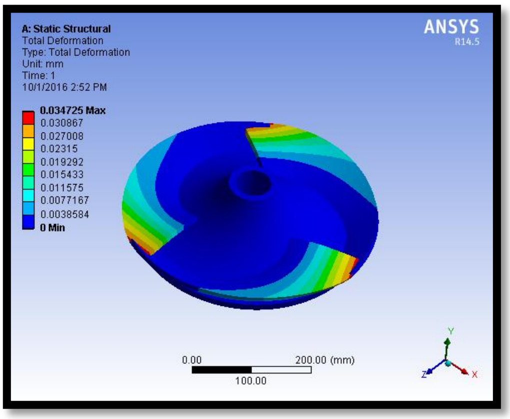

Fig.8 – Total Deformation for Steel

Maximum deformation 0.034725mm is obtained at end tip of blades due to high pressure is applied on blades and minimum deformation 0.0038584mm is at hub of a pump

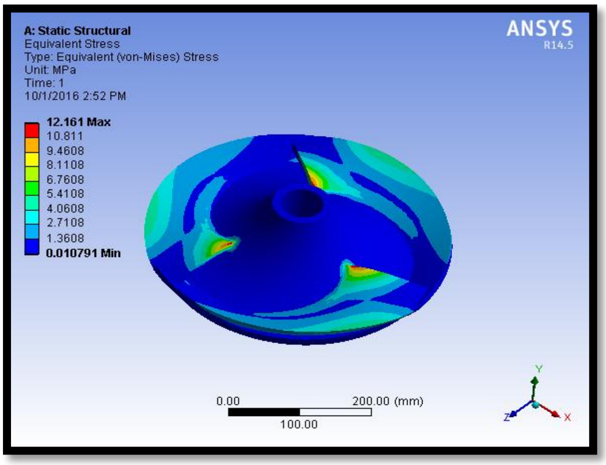

Fig.9 – Equivalent Stress for Steel

Maximum stress 12.161 MPa is obtained at tip of blades due to high pressure is applied on blades and minimum stress 0.010791MPa is at hub of a pump

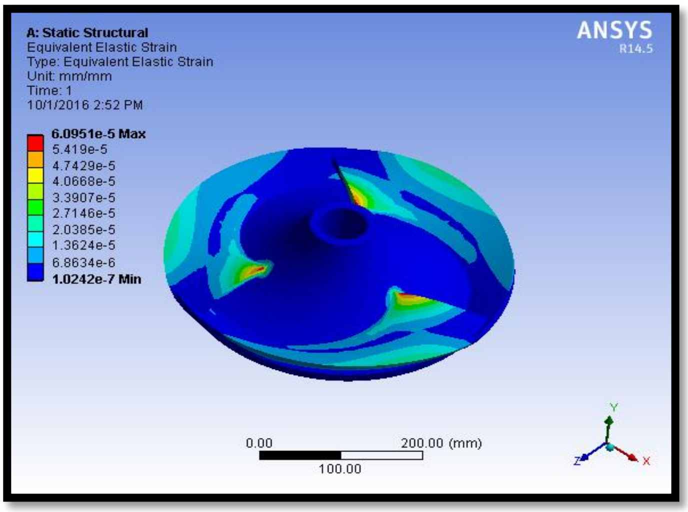

Fig.10 – Equivalent Elastic Strain for Steel

Maximum strain 6.0951e-5 is obtained at tip of blades due to high pressure is applied on blades and minimum strain 1.0242e-7 is at hub of a pump

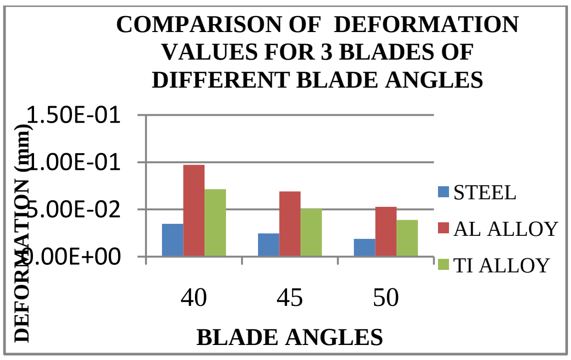

Fig.11 The Deformation decreases with increasing angle of blades

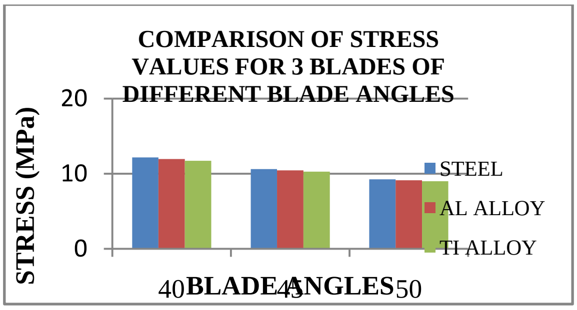

Fig.12 The Stress decreases with increasing angle of blades

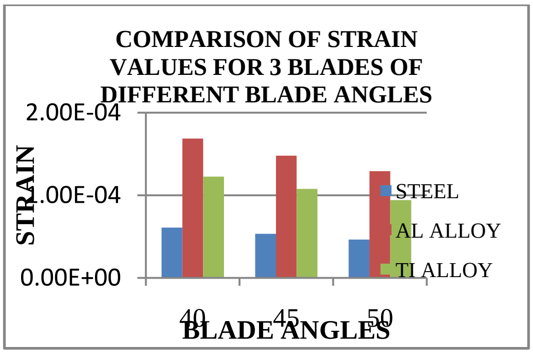

Fig.13 The Strain decreases with increasing angle of blades

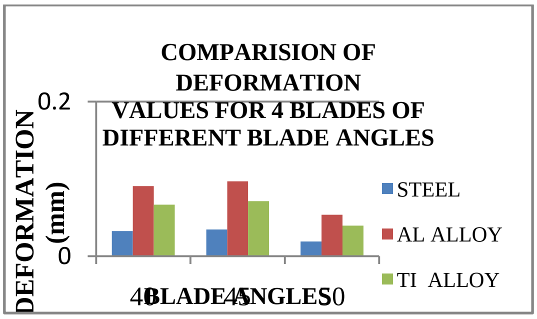

Fig.14The Deformation decreases with increasing angle of blades

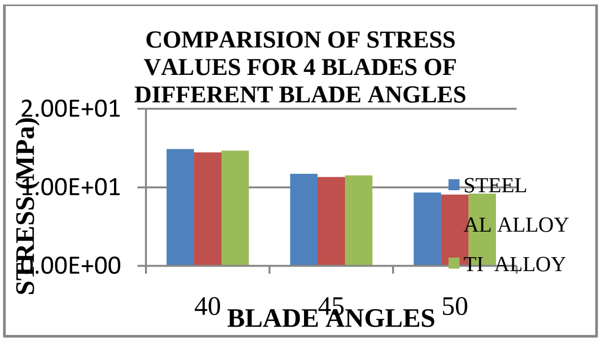

Fig.15 The Stress decreases with increasing angle of blades

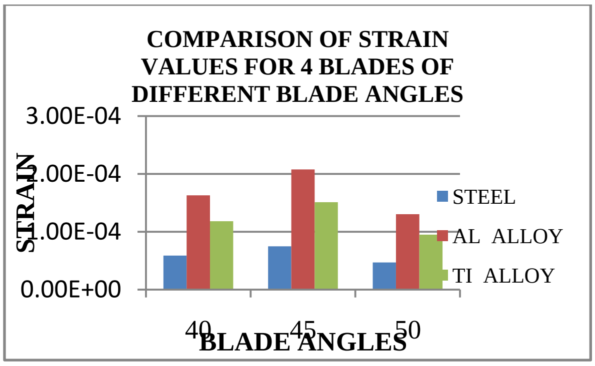

Fig.16 The Strain decreases with increasing angle of blades

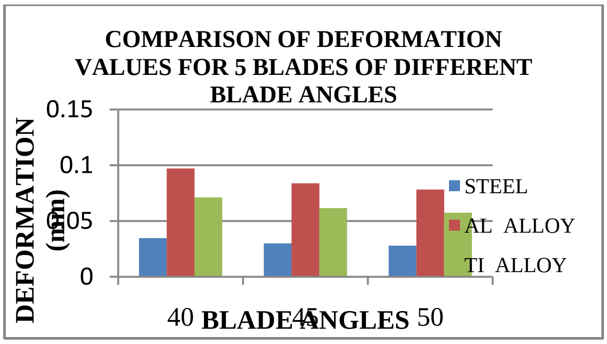

Fig.17 The Deformation decreases with increasing angle of blades

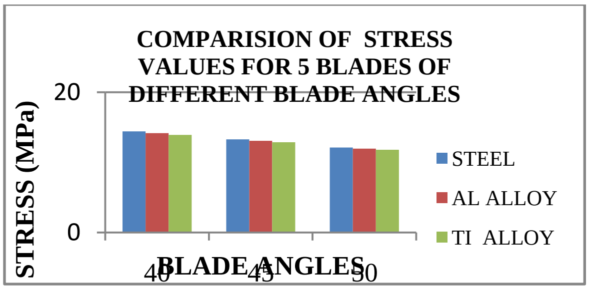

Fig.18 The Stress decreases with increasing angle of blades

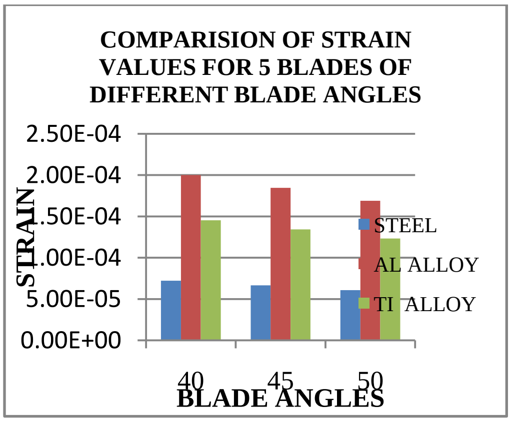

Fig.19 The Strain decreases with increasing angle of blades

OPTIMIZATION OF PARAMETERS USING MINITAB SOFTWARE

Taguchi parameter design for optimizing parameters

In order to identify the parameters affecting the characteristics, the following parameters are selected for the present work: No. of Blades (A), Blade Angle (B) and Material (C).

Selection of Orthogonal Array

The parameters and their values are given in table. It was also decided to study the three factor interaction effects of parameters on the selected characteristics.

Table. 5: CFD analysis result for 5 blades

FACTORS	**PARAMETERS**	**LEVEL 1**	**LEVEL2**	**LEVEL 3**
A	No. of Blades	3	4	5
B	Blade Angle	40	45	50
C	Material	Steel	Titanium	Aluminum

The stress values from the analysis are taken as the response for characteristic smaller-the-better.

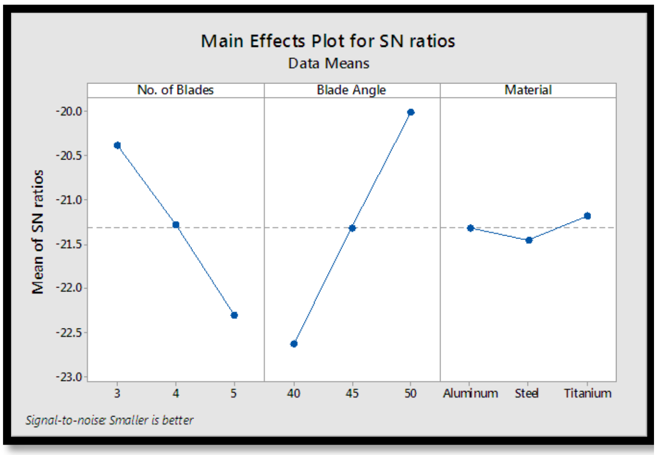

Fig.20. Main Effects Plot for S/N ratios - Smaller is better

Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The stress values are considered as the quality characteristic with the concept of "the smaller-the-better". The S/N ratio for the smaller-the-better is:

$S/N = -10 * \log(\Sigma(Y^2)/n))$

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration above Eqn. with the help of software Minitab 17.

Analysis and Discussion

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the factors is the level with the greatest value.

No. of Blades - The optimal blades is 3.

Blade Angle - The optimal blade angle is 50^0.

Material – The optimal material is Titanium.

CONCLUSION

By observing the CFD results, the pressure, velocity and the mass flow rate is increasing by increasing the blade angle. The values are increasing by increasing number of blades. By observing structural analysis results, the deformation and stress values are decreasing by increasing number of blades. The total deformation is less for 50^0 blade angle when Steel alloy is used. The stress values are less for 50^0 blade angle when Titanium alloy is used.

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