"PERFORMANCE ANALYSIS AND OPTIMIZATION OF CENTRIFUGAL FAN"

Research Paper

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ABSTRACT

Fans are one of the types of turbo machinery which are used to move air continuously with slight increase in static pressure. Fans are widely used in industrial and commercial applications from shop ventilation to material handling, boiler applications, transporting gas or materials and most use in the HVAC industry today. The performance of the centrifugal fan is analyzed by its performance curves. The flow between the blades is always complicated for understanding. The losses created like entry losses at impeller, impeller losses, leakage loss and volute losses always occur in the centrifugal fan. Hence, by reducing the losses of centrifugal fan, performance of centrifugal fan has been improved.

To improve the efficiency of centrifugal fan, various analytical softwares are available which give the information about complex flow inside the centrifugal fan. The model of the centrifugal fan is made in Solid work 2009 (made by Dassault System Company). Performance analysis has been carried out by experimental and ANSYS CFX software.For the analysis backward-swept blade centrifugal fan having 12 number of blade is selected. Then experimental readings has been collected and analysis by software. Then experimental readings and software analysis results compared. Now, the parameters like inlet blade angle, outlet blade angle, number of blade have been changed for analysis. From results obtained of by changed geometry has been optimized by Tauguchi method.

Keywords: Centrifugal fan, Computational Fluid Dynamics (CFD) analysis, and Optimization with taguchi method.

1. INTRODUCTION

A centrifugal fan is a mechanical device for moving air or other gases. These fans increase the speed of air stream with the rotating impellers. Centrifugal fan use a rotating impeller to move air first radially outward towards by centrifugal action, and then tangentially away from the blade tips. As the air moves from the impeller hub to the blade tips, it gains kinetic energy. This kinetic energy is then converted to a static pressure and increase the pressure of the air or gas stream which in turn moves them against the resistance caused by ducts, dampers and other components. Industrial application of fans are to supply ventilation or combustion air, to circulated air or other gases through equipment and the exhaust air or other vapours from equipment.

Meakhail and Park [1] have studied the impeller-diffuser-volute casing interaction in centrifugal fan experimentally and validated it numerically. They have used steady analysis results as an initial parameter for unsteady analysis later on. N. Vibhakar and Masutage [2] experimented on a backward curved radial tipped blade centrifugal fan. The centrifugal fan designed by unified method is simulated using computational fluid dynamics (CFD) approach. O. P. Singh [3] discussed in this paper, effect of geometric parameters of a centrifugal fan with backward- and forward-curved blades has been investigated. The results show that increase in the number of blades increases the flow coefficient accompanied by increase in power coefficient. K. Vasudeva Karanth [4] Study about the Effect of Radial Gap on impeller-diffuser flow of a centrifugal Fan. With the development of PIV and CFD tools such as moving mesh techniques and numerical methodology involving moving mesh technique is used. Li Chunxi [5] discussed about the influence of enlarged impeller in unchanged volute on G4-73 type centrifugal fan performance is investigated in this paper. Result Show that the total pressure increases after the impeller enlargement.

In this course of work, fan geometry is obtained as per solid works. CFD analysis carried out in this work is to understand the impeller interaction at parameter number of blade , inlet angle, outlet angle and evaluate the flow behaviour inside centrifugal fan by using ANSYS software.

2. METHODOLOGY:

- For the analysis backward-swept centrifugal fan having 12 number of blade is selected.
- Following data is collected for the given problem is shown in table 1.

Table 1: DATA COLLETED

Part Name	Parameters	Symbol	Dimensions
Impeller	Inlet diameter	d_1	276 mm
	Outlet diameter	d_2	425 mm
Blade	Number	N	12
	Inlet blade angle	β_1	20.5^0
	Outlet blade angle	β_2	26.5^0
	Width	b_{blade}	107 mm
	Thickness	t_{blade}	5mm
Volute Casing	Diameter	D_1	253mm
		D_2	286mm
		D_3	324mm
		D_4	328mm
		D_5	449mm
		D_6	575mm
		D_7	599 mm
Impeller	Rotation Speed(rpm)	N	2850rpm

The model of centrifugal fan is made in solid works 2009 (made by Dassault system company).Then Experimental reading to be collected.Experimental reading will be analyzed in software.Experimental and software result will be compared. And than Optimization for the given problem will be carried out by Tauguchi method.

Fig 1: Experimental picture of Centrifugal fan

Table 2: Changed parameters of impeller

Sr. no.	Parameters	Existing data	Case-1	Case-2
1	Number of blade	12	10	14
2	Blade inlet angle	20.5°	18.5°	22.5°
3	Blade outlet angle	26.5°	24.5°	28.5°

3 MODELLING OF CENTRIFUGAL FAN :

- 3D MODELS OF CENTRIFUGAL FAN:

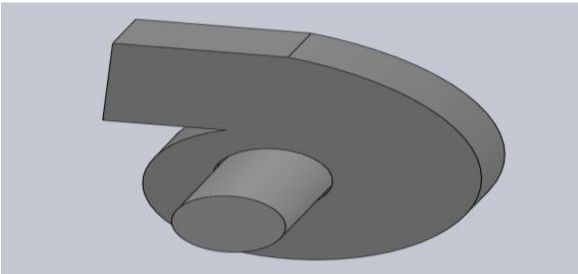


Figure 2- Cavity Model of Centrifugal Fan

Cavity Model of Impeller:

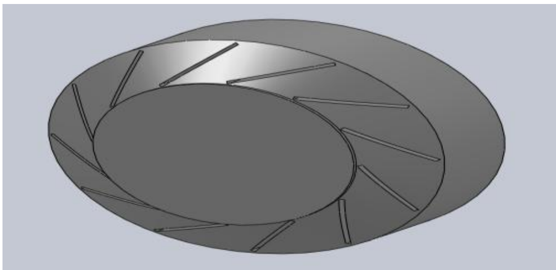


Figure 3- Cavity Model of Impeller

4. CFD ANALYSIS OF CENTRIFUGAL FAN:

- PROCEDURE OF CFD ANALYSIS:
  1. Save above Cavity model of centrifugal fan fig 1in *.IGES Format for Importing into ANSYS Workbench Mesh Module for Meshing.
  2. 2.Meshing of Centrifugal Fan:

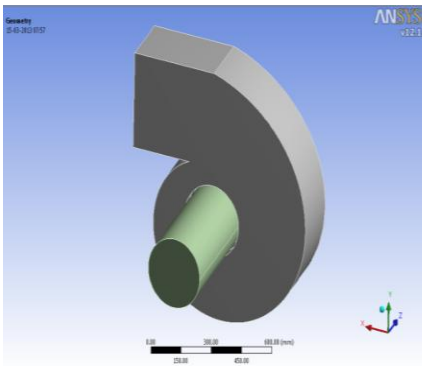


Fig 5: Cavity model in ANSYS Workbench

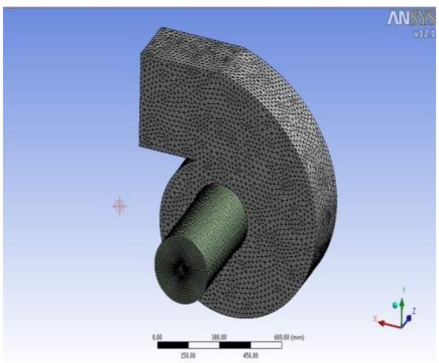


Fig 6: Meshing of Centrifugal fan

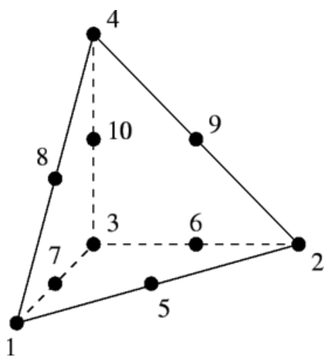


Fig 7: Tetrahedral Element

- Type of Meshing: - 3D
- No. of Elements: - 441571

No. of Nodes: - 139745
Type of Element: - Tetrahedral

3.Save Above model in *.CMDB Format for importing into ANSYS CFX Pre shown in fig 8.
4.Define Domain for Pipe.
5. Define Heat Transfer and Turbulence Model.
6.Define Domain for Impeller.
7.Define Domain for Casing.
8. Define Inlet for Centrifugal Fan.
9.Define Outlet for Centrifugal Fan.
10. Define Interface between Pipe and Impeller.
11. Define Interface between Pipe and casing.
12. Define Solver Control Criteria for Interface between Impeller and Casing.
13.Run the Analysis.
14. Get the Results.

- RESULTS OF CENTRIFUGAL FAN ANALYSIS:

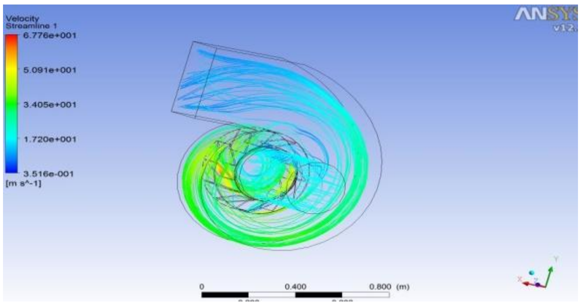


Fig 9: Velocity Streamlines

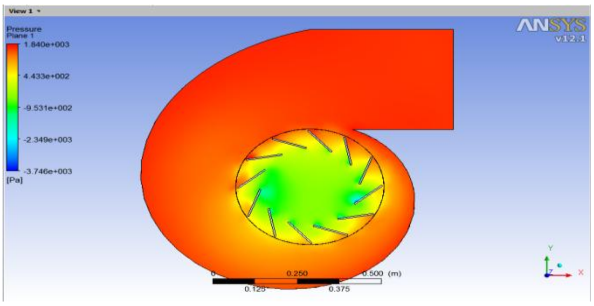


Fig 10: Pressure Contour for all Domain

- Range of pressure for all domain contour = -3746 to 1840 Pa

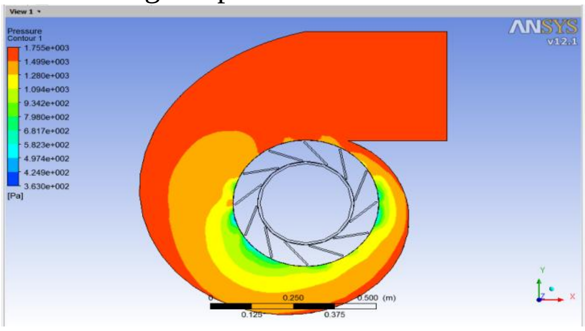


Fig 11: Pressure Contour for Casing

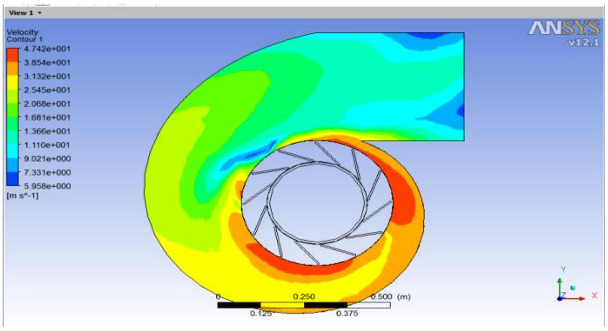


Fig 13: Velocity Contour for Casing

- Range of Outlet pressure contour for casing = 363 to 1755 Pa
- Range for Outlet velocity contour for casing = 5.958 to 47.42 m/s

- **Comparison of Experimental with CFD Analysis Results:**

Table No 4: Results Analysis

Sr No.	Description	Pressure (Experimental)	Pressure (CFD)	Percentage Variation
1	Centrifugal Fan	1741Pa	1755 Pa	0.8

5. OPTIMIZATION BY TAGUCHI METHOD:

Taguchi's technique has been popular for parameter optimization in design of experiments (DOE) for decades due to its excellent characteristics.

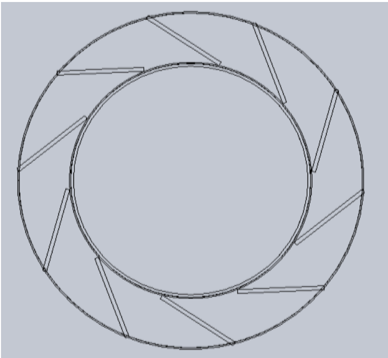
- **COMBINATION:**

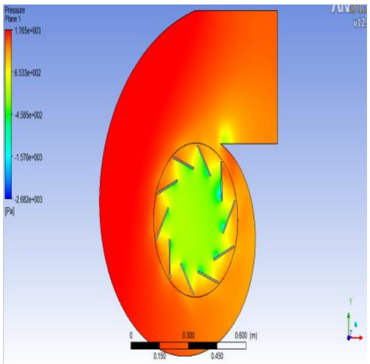
Table 5: Orthogonal Array L09 of Taguchi Method using Minitab Software

NO.	Inlet Angle	Outlet Angle	No. of Blades
Fan 1	18.5	24.5	10
Fan 2	18.5	26.5	12
Fan 3	18.5	28.5	14
Fan 4	20.5	24.5	12
Fan 5	20.5	26.5	14
Fan 6	20.5	28.5	10
Fan 7	22.5	24.5	14
Fan 8	22.5	26.5	10
Fan 9	22.5	28.5	12

Case 1:

NO.	Inlet Angle	Outlet Angle	No. of Blades
Fan 1	18.5	24.5	10





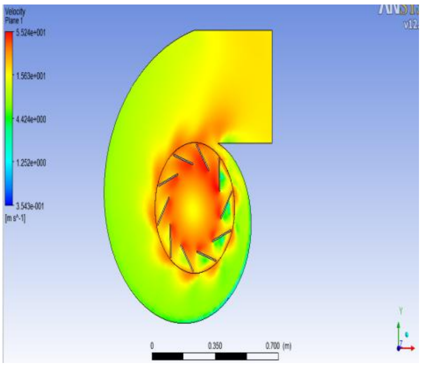
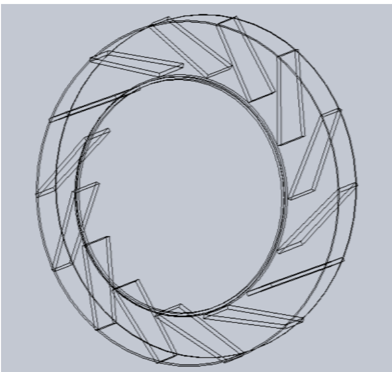


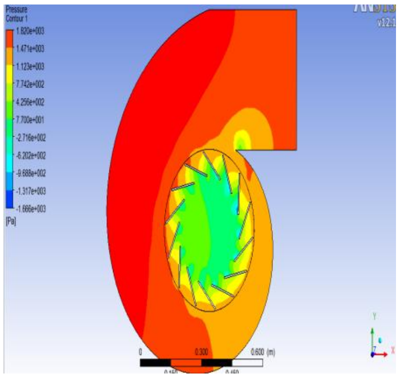
Fig 14:Cavity model of fig 15: Outlet Pressure contour Fig16: Outlet Velocity
contour modified modified Impeller-case

- ➢ Range of Outlet Pressure contour for full domain = -2682 to 1765 Pa
- ➢ Range of Outlet velocity contour for full domain = 35.43 to 55.24 m/s

Case 5:

NO.	Inlet Angle	Outlet Angle	No. of Blades
Fan 5	20.5	26.5	14





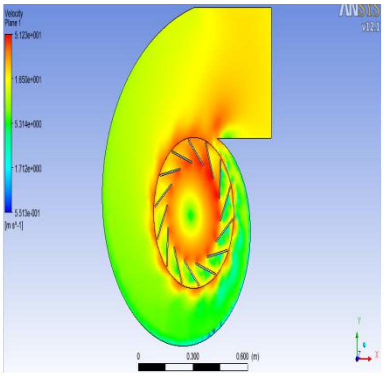


Fig 17: Cavity model of Fig 18: Outlet Pressure contour Fig 19: Outlet Velocity contour
modified Impeller

- ➢ Range of Outlet Pressure contour for full domain = -1666 to 1820 Pa
- ➢ Range of Outlet velocity contour for full domain = 55.13 to 51 .23 m/s

So, simillarly analysis of all the remaining case of modified centrifugal fan and Get the results of this analysis shown in table no 7.

- **RESULT TABLE OF TAGUCHI METHOD**:

Table 6: Result table of analysis

No. Of fan	Inlet Angle	Outlet Angle	No. of Blades	Outlet Pressure(Pa)	Inlet pressure(Pa)	Outlet Velocity (m/sec)	Pressure Rise (Pa)	efficiency
1	18.5	24.5	10	1765	-579	15.63	2344	32.80
2	18.5	26.5	12	1789	-579	16.61	2368	32.36
3	18.5	28.5	14	1815	-579	16.43	2394	31.90
4	20.5	24.5	12	1792	-579	12.25	2371	32.31
5	20.5	26.5	14	1820	-579	16.50	2399	31.81
6	20.5	28.5	10	1785	-579	14.28	2364	31.81
7	22.5	24.5	14	1808	-579	16.28	2387	32.02
8	22.5	26.5	10	1752	-579	14.00	2331	32.04
9	22.5	28.5	12	1763	-579	16.25	2342	32.84

6. RESULT AND DISCUSSION:

- **Taguchi Analysis of outlet pressure by Using Minitab Software:**

Table 7: Response Table for Means of outlet pressure

Level	**Inlet Angle (Degree)**	**Outlet Angle(Degree)**	**No. of Blades**
1	1790	1788	1767
2	1799	1787	1781
3	1774	1788	1814
Delta	25	1	47
Rank	**2**	**3**	**1**

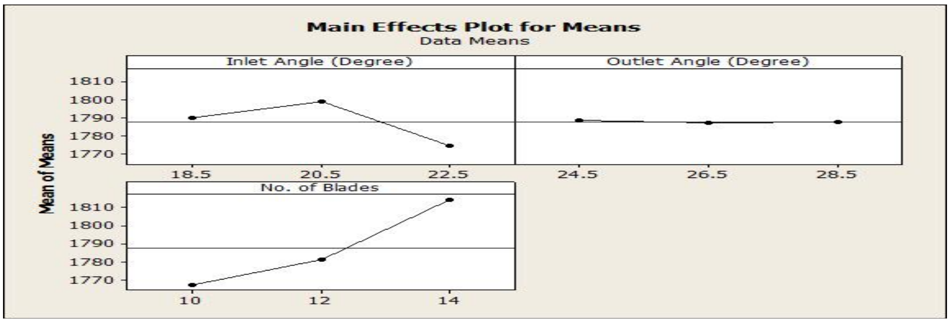


Figure- 20: Main Effects Plot for Means of outlet pressure

From table 8, mean is average value for reading taken for parameter. From graph, mean value is maximum (1799) for 20.5˚ inlet angle and minimum (1774) for 22.5˚ inlet angle. Mean value is maximum (1788) for 24.5˚ or 28.5˚ outlet angle and minimum (1787) for 26.5˚ outlet angle. Mean value is maximum (1814) for14 no. of blade and minimum (1767) for 10 no. of blade.

Delta is difference of maximum value and minimum value. Delta value is maximum (47) for no. of blade and minimum (1) for outlet angle. Delta value for inlet angle is between other two parameter and it is (25).So that effect of no. of blade is maximum and effect of outlet angle is minimum on fan outlet pressure.

Table 8: Response Table for Signal to Noise Ratios Larger is better

Level	Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades
1	65.05	65.05	64.95
2	65.10	65.04	65.01
3	64.98	65.05	65.17
Delta	0.12	0.01	0.23
Rank	**2**	**3**	**1**

Response curve analysis is determining effect of parameter and their optimum set of control parameters. Figure shows response at each factor level. The S/N Ratio for the different performance responses is calculating at each factor.

The S/N Ratio for different performance response is calculated at each factor level and the average effect is determined by taking the total of each factor level and divided by the number of data points in the total. The greater difference between S/N ratio values the levels, the parametric influence will be much. The parameter level having the highest S/N ratio corresponds to the sets of parameters indicates highest performance.

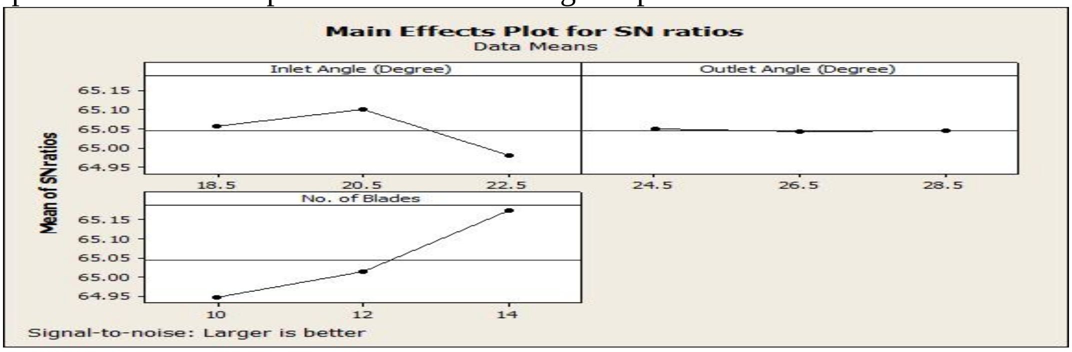


Figure- 21: Main Effects Plot for S/N ratios of outlet pressure

The optimum setting is determined by choosing the highest S/N ratio with the level. Fig 21 the response curve for S/N ratio, the highest S/N ratio is observed at 20.5˚ inlet angle (65.10), 24.5˚ or 28.5˚ outlet angle (65.05) and No. of blade 14 (65.17), which are optimum parameter setting for highest outlet pressure. From delta values is maximum (0.23) for No. of blade and minimum (0.01) for outlet angle. Show that Parameter No. of blade is most significant parameter and outlet angle is least significant for fan outlet pressure.

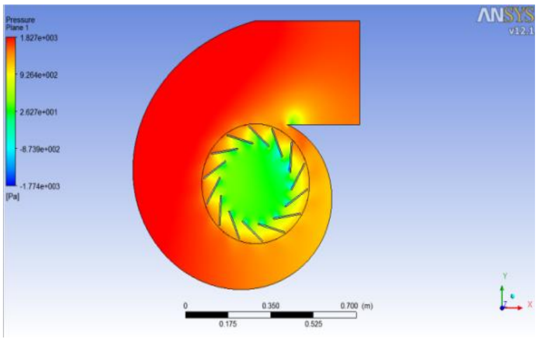
Table 9: Factor Levels for Predictions of outlet pressure

Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades
20.5˚	24.5˚	14

Table 10: Taguchi Predicted Results for fan of outlet pressure

Pressure	S/N Ratio
1826.33	65.233

Using optimum set of parameters, which is achieving by Minitab software for taguchi method of optimization is used for analysis of validation of parameter. The result different parameter is obtained by analysis is compared with software predicated value for maximum outlet pressure.



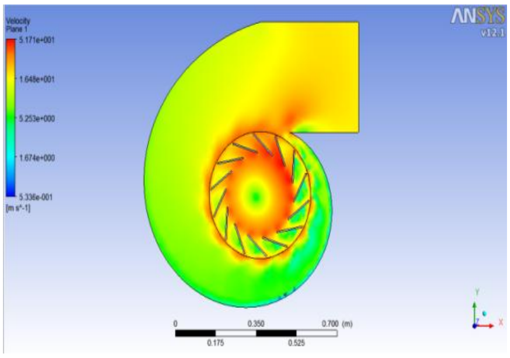


FIG 22 : Outlet pressure for optimizad impeller FIG 23:Outlet velocity for optimizad impeller

- Range of Outlet pressure for full domain contour = -1774 to 1827 Pa
- Range of Outlet velocity for full domain contour = 53.36 to 51.71 m/s

Table 11: Validation Results for outlet pressure

Modified Impeller	Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades	Outlet Pressure (Pa)	Outlet velocity m/s
Validation-1	20.5˚	24.5˚	14	1827Pa	16.48m/s

Analysis is done for above set of parameter is shown in fig 22& 23 gives performance as shown in above table 12. It is outlet pressure is 1827 Pa. This analysis value is nearer our predicted value 1826.33 Pa. So, that our analysis going to a right way.

- **Taguchi Analysis for fan Efficiency by Using Minitab Software:**

Table 12: Response Table for Means of Efficiency

Level	Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades
1	32.35	32.38	32.22
2	31.98	32.07	32.50
3	32.30	32.18	31.91
Delta	0.38	0.31	0.59
Rank	**2**	**3**	**1**

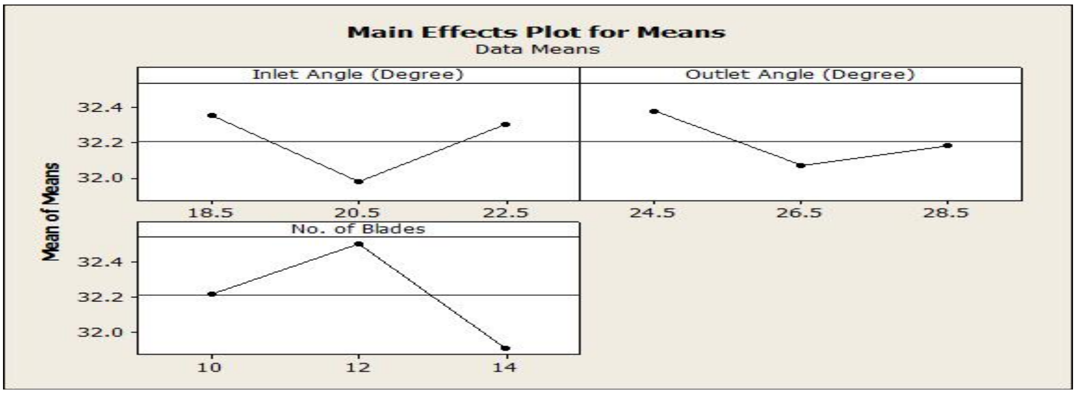


Figure-24: Main Effects Plot for Means of Efficiency

From table 13, mean is an average value for reading taken for parameter. From graph, mean value is maximum (32.35) for 18.5˚inlet angle and minimum (31.98) for 20.5˚ inlet angle. Mean value is maximum (32.38) for 24.5˚ outlet angle and minimum (32.07) for 26.5˚ outlet angle. Mean value is maximum (32.50) for 12 No. of blade and minimum (31.91) for 14 No. of blade.

Delta is difference of maximum value and minimum value. Delta value is maximum for No. of blade (0.59) and minimum (0.31) for outlet angle. Delta value for inlet angle is between other two parameter and it is (0.38).So that effect of No. of blade is maximum and effect of outlet angle is minimum on fan efficiency.

Table 13: Response Table for S/N Ratios for Means of Efficiency

Level	Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades
1	30.20	30.20	30.16
2	30.10	30.12	30.24
3	30.18	30.15	30.08
Delta	0.10	0.08	0.16
Rank	**2**	**3**	**1**

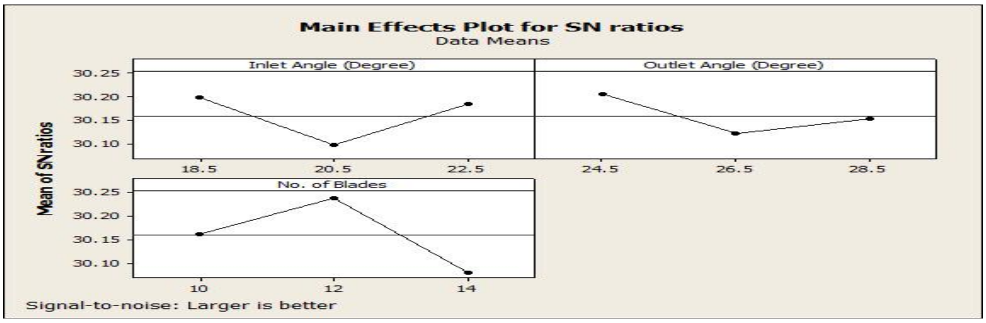


Figure- 25: Main Effects Plot for S/N Ratio for Efficiency

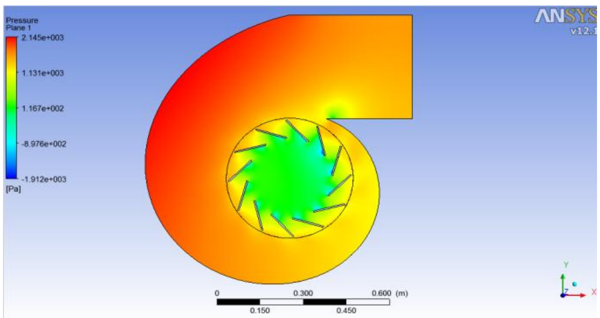
The optimum setting is determined by choosing the highest S/N ratio with level. Fig.25, the response curve for S/N ratio, the highest S/N ratio is observed at inlet angle 18.5˚ (30.20), outlet angle 24.5˚ (30.20) and No. of blade 12 (30.24), which are optimum parameter setting for fan efficiency. From delta value is maximum (0.16) for No. of blade and minimum (0.8) for outlet angle. Parameter No. of blade is most significant parameter and outlet angle is least significant for fan efficiency.

Table 14: Factor Level for Predictions for Efficiency

Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades
18.5˚	24.5˚	12

Table 15: Predicted Results of Efficiency for centrifugal fan

Efficiency	S/N Ratio
32.81	30.321



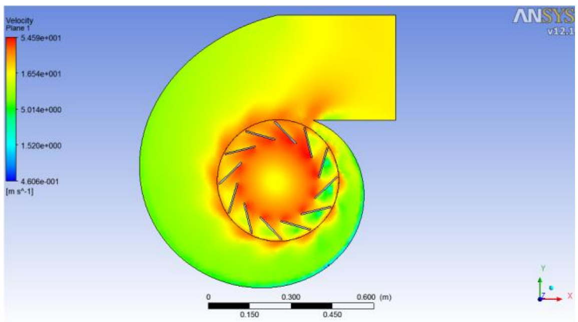


FIG 26: Outlet pressure FIG 27: Outlet Velocity

for optimizad impeller for Efficiency

- Range of Outlet pressure for full domain contour = -1912 to 2145 Pa
- Range of Outlet velocity for full domain contour = 0.46 to 54.59 m/s

Table 16: Validation Results of Efficiency for centrifugal fan

Modified Impeller	Inlet Angle (Degree)	Outlet Angle (Degree)	No. of Blades	Outlet Pressure (Pa)	Outlet velocity m/s	Efficiency
Validation-2	18.5˚	24.5˚	12	2145Pa	16.54 m/s	32.57

Analysis is done for above set of parameter shown in fig 26 & 27 gives performance as shown in above table 17. It is Efficiency is 32.57. This analysis value is nearer our predicted value 32.81. So, that our analysis going to a right way.

7. CONCLUSION

The following conclusions are derived from the analysis:

- The software predicated outlet pressure is 1826 Pa, pressure rise is 2405 Pa, and efficiency is 32.81%. The value of validation analysis of centrifugal fan outlet pressure is 1827 Pa and efficiency is 32.81%. Validation analysis value compared with predicated value.
- These analysis values of centrifugal fan outlet pressure and efficiency are very closer to the predicated values.
- Result obtained from validation analysis using optimum parameter combination gives excellent agreement with predicated results.
- By the taguchi in the centrifugal fan as increase the number of blade increase the pressure and efficiency. And also inlet angle decrease and outlet angle increase so that increase the pressure of the fan.
- Also prove that taguchi parameter concept is more powerful and efficient tool for maximize pressure (head) and efficiency.

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