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Optimization and analysis of bend - diffuser geometry using CFD through Taguchi method

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ABSTRACT

Diffuser is an essential element of fluid flow machines, the study of flow nature through diffuser is essential in understanding and improving the performance. The primary objective of this analysis is to examine the bend-diffuser and to optimize the dimension of the diffuser so that the diffuser efficiency will be maximum. The velocity field at the exit of a bend diffuser system is mostly not uniform; fluctuation of pressure and its loss are high. The total pressure loss in the diffuser depends on the entry condition of the fluid and geometrical parameters. In this work, diffuser is analysed for a given inlet condition and the geometry is optimized to obtain maximum efficiency. The diffuser is designed in GAMBIT and analysed using FLUENT 6.3. Optimization of the geometry is done using Taguchi technique by taking the parameters such as diffuser angle, diffuser length, and spacer length as control factors. Using larger the better quality characteristics, the diffuser efficiency was obtained. Using Taguchi's orthogonal array for quality design concept, the optimum diffuser geometry is 7.5° for diffuser angle, Diffuser length is 490 mm, and Spacer length is 350 mm. The above optimum condition was used to obtain the maximum efficiency for the Bend diffuser configuration.

KEY WORDS: Taguchi, Pressure and Velocity Variation, Diffuser.

1. INTRODUCTION

S- Shaped diffuser was studied by Gavin, Lee (2013) and also the shear stress turbulence model using ANSYS-CFX. The velocity contour was flattening in early divergent section in the outer surface; there will be highest velocity region. Among all, S-Shaped diffuser duct has good performance characteristics than the cross-sectional area expansion over its entire length.

Ernesto Benini (2006) studied the behaviour of a centrifugal compressor of a gas turbine for small scale power production. They established a procedure to improve diffuser performance. Performance investigation was carried out at different rotating speed at different operating points. The dimension of the diffuser used in compressor is optimized by using evolutionary algorithm together with CFD calculation.

Trevor J. Cox (2006) studied the diffuser in flow path between the high & low pressure turbine and their different effects. The dimension of the diffuser were optimized i.e. diffuser length and hence the engine weight reduction was achieved. The reduction of weight can be attained by keeping exit vanes as small as possible. Engine weight can be reduced by applying the concept of turning turbine frames.

Design of Bend-Diffuser

Diffuser specification:

Length of the diffuser	= 490 mm
Diffuser angle	= 9°
Spacer Length	= 450 mm
Diameter of bend tube	= 100 mm
Cross section of the diffuser	= Circular

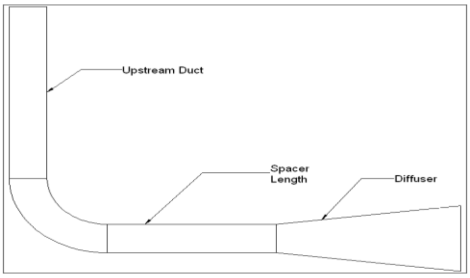


Figure.1. Schematic diagram of Bend Diffuser

Diffuser Efficiency: The Diffuser efficiency or effectiveness is given by

$$\eta = \frac{\text{Static pressure rise in actual process}}{\text{Static pressure rise in isentropic process}}$$

$$\eta = \frac{C_{pa}}{C_{ps}}$$

The Static Pressure rise in isentropic Process is given by

$$C_{ps} = 1 - \left(\frac{C_2}{C_1}\right)^2 = 1 - \left[\frac{1}{A_R{}^2}\right]$$

Where C_1 = Inlet Velocity of the Diffuser in m/s

C_2 = Outlet Velocity of the Diffuser in m/s

A_R = Area Ratio of the Diffuser

The Static Pressure rise in Actual Process is given by

$$C_{pa} = C_{ps} - \frac{\Delta p_0}{.5\ \rho c_1{}^2}$$

For the incompressible flow through the diffuser the energy equation is given by

$$\frac{p_1}{\rho} + \frac{c_1{}^2}{2} = \frac{p_2}{\rho} + \frac{c_2{}^2}{2} + \frac{\Delta p_0}{\rho}$$

Where ρ = Density of the air in kg/m^3

P_1 = Pressure at the inlet of the Diffuser in Pascal

P_2 = Pressure at the outlet of the Diffuser in Pascal

Taguchi Approach: The main principle of robust design was to increase quality of the product by reducing effects of causes of variation. It is attained by enhancing the product and process variables to create the performance slightly sensitive to several causes of variation, a process called parameter design.

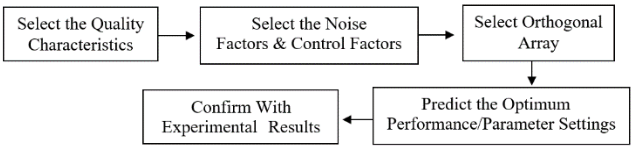


Figure.2. Steps in Taguchi Parameter Design

Orthogonal arrays: Orthogonal array is factorial matrix, which assures a stable comparison of levels of a factor (or interaction of factors).This matrix of numbers in rows and columns, here each row symbolizes the factor level in each run. Every column signifies specific factor that can be changed from each run. The array is called orthogonal because all columns can be evaluated independent of one another an attempt was done in this wok with L_9 orthogonal array.

Table.1. Control Assignments

CASE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
A	1	1	1	2	2	2	3	3	3
B	1	2	3	1	2	3	1	2	3
C	1	2	3	2	3	1	3	1	2
D	1	2	3	3	1	2	2	3	1

Control factors and levels: A detailed study on the bend diffuser system reveals that most significant factor for reducing pressure loss were identified as Diffuser angle, Length of diffuser & Spacer length.

Table.2. Control Factors and Levels

Factors	Factor Levels		
	Level-1	Level-2	Level-3
Diffuser Angle(Degree)	7.5^0	9^0	12^0
Length of the Diffuser(mm)	470	490	510
Spacer Length(mm)	450	400	350

Pareto anova: The purpose of ANOVA is to examine the geometrical parameters that significantly affect the performance characteristic. PARETO ANOVA has been implemented here, which is simple when compared to ANOVA technique. PARETO ANOVA shows contribution level of parameters on the measured response.

Computation of pareto anova: This method enables the significance of factors and allows the optimum level of factors to be obtained. PARETO ANOVA for three factors with three levels is taken for this problem.

Table.3. Pareto Anova

Factors	**A**		**B**	**C**	**Total**
Sum of factors	1	A1	B1	C1	Sum of 1,2,3, levels
	2	A2	B2	C2	
	3	A3	B3	C3	
Sum of squares of difference	S_A $(A1-A2)^2+(A1-A3)^2+(A2-A3)^2$		S_B $(B1-B2)^2+(B1-B3)^2+(B2-B3)^2$	S_C $(C1-C2)^2+(C1-C3)^2+(C2-C3)^2$	S_T $(S_A+S_B+S_C)$
Contribution ratio (%)	$(S_A/S_T)x100$		$(S_B/S_T)x100$	$(S_C/S_T)x100$	100

Computional Fluid Dynamics: Domain options and boundary conditions has been given to the grid using Fluent pre-processor.

Domain options:

- Reference pressure : 0 Pa
- Solver : energy equation, continuity equation
- Initial pressure :101325 Pa
- Simulation type : Steady state

Boundary Conditions: The flow is assumed to be steady state in a static frame of reference. Incompressible and Newtonian fluid was selected. The flow direction was specified as axial direction frame of reference. The wall next to the fluid is hydro dynamically smooth.

Inlet Condition: The inlet flow region specified subsonic and the velocity of 40m/s is specified. The wall has been identified as a stationary frame.

Outlet Condition: The pressure outflow is identified at inlet condition.

Post-Processing: On completion of boundary conditions the flow analysis was executed using Fluent 5/6 solver.

Problem Solving Steps - Flow Chart

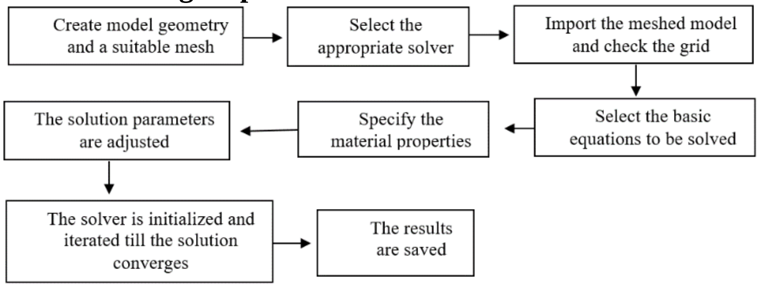


Figure.3. Flow chart for problem solving

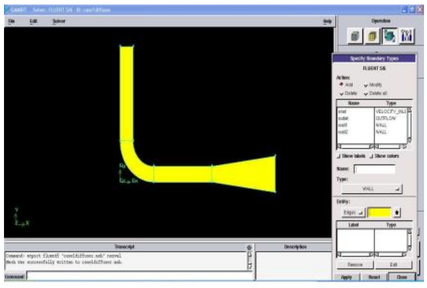
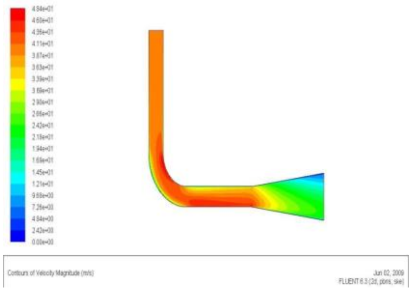


Figure.4. Grid model of the diffuser

Figure.5. (a) case-1 Pressure Distribution



(b) Case-1Velocity Distribution

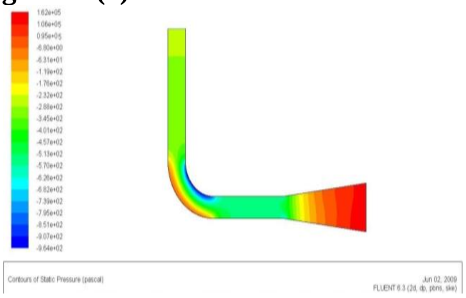
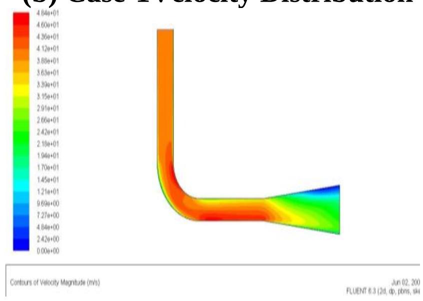


Figure.6. (a) Case-2 Pressure Distribution



(b) Case-2 Velocity Distribution

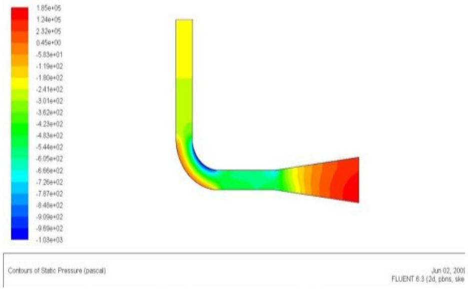
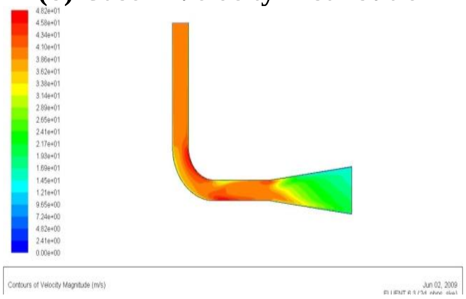


Figure.7. (a) case-3 Pressure Distribution



(b) Case-3 Velocity Distribution

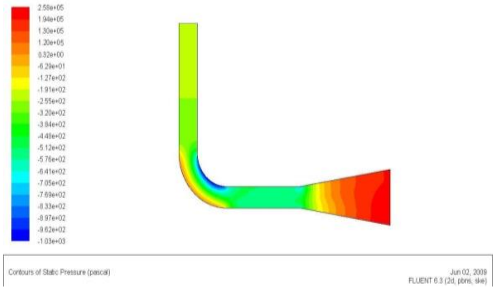
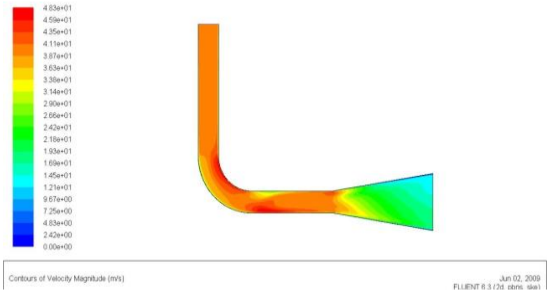


Figure.8. (a) Case-4 Pressure Distribution



(b) Case-4 Velocity Distribution

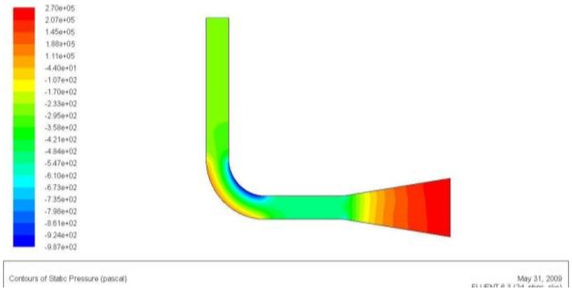
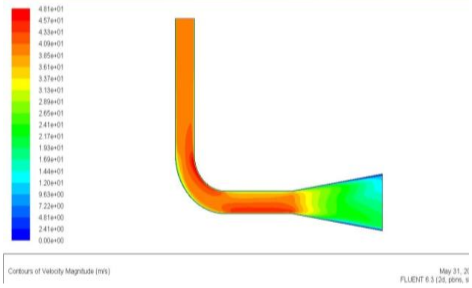


Figure.9. (a) Case-5 Pressure Distribution



(b) Case-5 Velocity Distribution

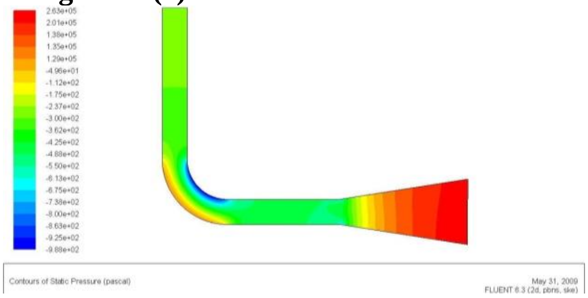
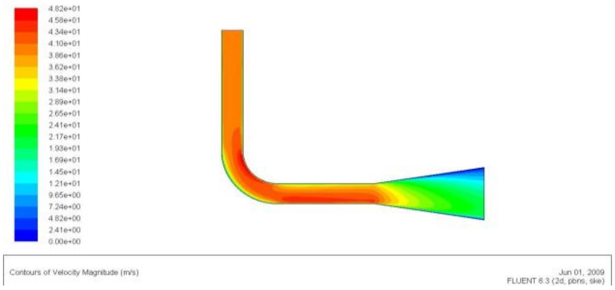


Figure.10. (a) Case-6 Pressure Distribution



(b) Case-6 Velocity Distribution

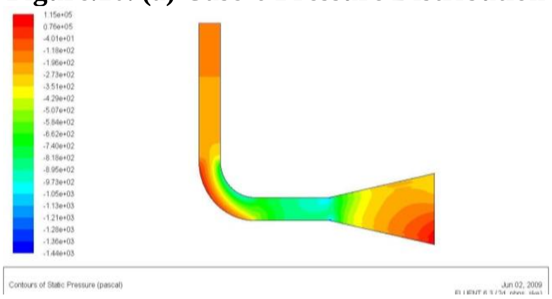
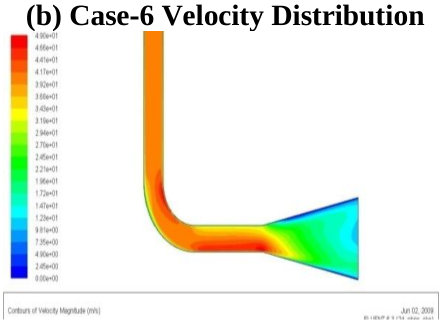


Figure.11. (a) Case-7 Pressure distribution



(b) Case-7 Velocity distribution

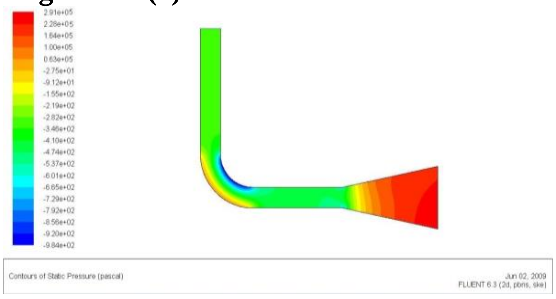
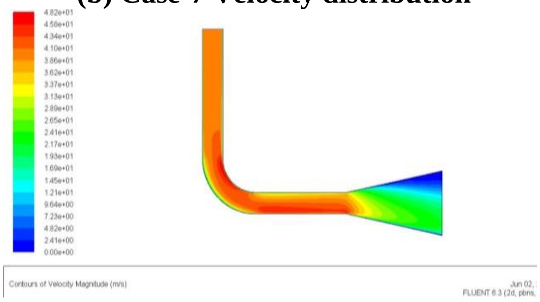


Figure.12. (a) Case-8 Pressure Distribution



(b) Case-8 Velocity Distribution

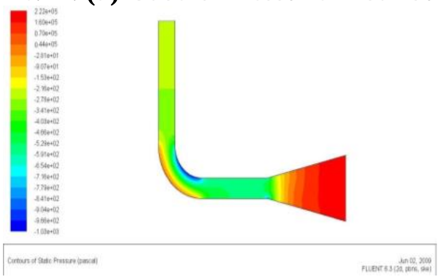
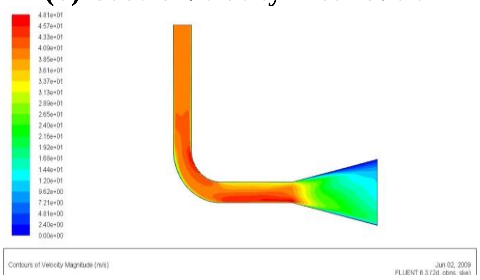


Figure.13. (a) Case-9 Pressure Distribution



(b) Case-9 Velocity Distribution

3. RESULTS AND DISCUSSION

The optimization of bend-diffuser geometry was carried out by taguchi technique. The results from the computational dynamics are used in arriving the optimum geometry of the bend diffuser to give the maximum efficiency. The results are listed below

Table.4. Experimental Results.

Diffuser angle (Degree)	Diffuser length (mm)	Pressure (Pascal)	Velocity (m/s)	Efficiency (η)
7.5	470	2.39×10^5	36.93	81.718
7.5	490	1.62×10^5	37.10	82.24
7.5	510	1.85×10^5	36.90	81.73
9	470	2.58×10^5	35.85	77.00
9	490	2.70×10^5	36.05	77.83
9	510	2.63×10^5	35.73	76.47
12	470	1.15×10^5	36.51	81.37
12	490	2.82×10^5	36.31	80.43
12	510	2.22×10^5	35.87	78.43
			Mean	79.69

Experimental Conditions and Calculation of S/N ratio: The experiments showed are based on $L_9 3^4$ orthogonal array. The simulated values are listed in table 5.2. Quality Characteristic – Larger the better.

Table.5. S/N ratio for Efficiency of the diffuser

Exp.No.	A	B	C	Efficiency	S/N
1	7.5°	470	450	81.71	38.25
2	7.5°	490	400	82.24	38.30
3	7.5°	510	350	81.73	38.25
4	9°	470	400	77.00	37.72
5	9°	490	350	77.83	37.822
6	9°	510	450	76.47	37.66
7	12°	470	350	81.37	38.20
8	12°	490	450	80.43	38.10
9	12°	510	400	78.43	37.88
				Mean	38.015

Table.6. PARETO ANOVA Results

Factors		A	B	C	E	Total
Sum of factors	1	**114.801**	113.85	114.01	113.95	342.17
	2	113.20	**114.23**	113.90	114.16	
	3	114.18	113.76	**114.26**	114.06	
Sum of Squares of differences		3.909	0.3734	0.2042	0.066	4.5526
Contribution ratio percentage		85.86	8.20	4.48	1.44	100
Optimum level		A1- Diffuser angle -7.5 degree				
		B2- Difuser length-490 mm				
		C3- Sapacer length-350 mm				

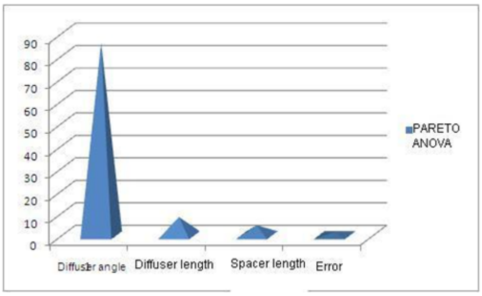


Figure.14. PARETO Diagram for Diffuser Efficiency

Pareto diagram shows the impact ratio for all control factors from the figure it is evident that factor A contributes 85.86 %, B contributes 8.20% and C contributes 4.48%.

Response Process Parameters: The average effects for each level of process parameters are listed in table 4.5

Table.7. Average effect of response for Efficiency

Factors Levels	A	B	C	E
1	81.89	80.02	79.53	79.32
2	77.1	80.16	79.22	80.02
3	80.07	78.87	80.31	79.72
Max - Min	4.79	1.29	0.78	0.70
Rank	1	2	3	4

Table.8. Average effect of response for S/N ratio

Factors Levels	A	B	C	E
1	38.26	38.05	38.00	37.98
2	37.73	38.076	37.96	38.05
3	38.06	37.92	38.08	38.02
Max - Min	0.53	0.15	0.12	0.04
Rank	1	2	3	4

4. CONCLUSION

The diffuser with a bend in the preceding section was analyzed and the geometry was optimized to maximize the diffuser efficiency using taguchi technique. The analysis was carried out in FLUENT and velocity & pressure variation were studied. The optimized parameter level affecting the diffuser geometry is found by taguchi method. The Diffuser angle is the factor which considerably affects the increase in efficiency. Spacer length has no impact on the objective much when compared to diffuser angle and length of diffuser.

Using Taguchi's orthogonal array for quality design concept, the optimum diffuser geometry is 7.5^0 for diffuser angle, Diffuser length is 490 mm, and Spacer length is 350 mm. The above optimum condition was used to obtain the maximum efficiency for the Bend diffuser configuration.

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