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Performance and Noise Prediction of Forward Impeller with Splitter Blades

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***Abstract* -In this work, a numerical simulation is performed to study centrifugal fan performance and noise; that is the flow characteristics and the noise prediction are taken into account. An industrial forward centrifugal fan of type (9-19 No. 4A) is used as a base fan. To enhance the performance of the fan and the noise emission, two modifications are made to the impeller of the base fan. The numerical analysis results indicated that adding of splitters blades in different size and position improved the flow field. Increasing size of the splitters blades increase efficiency and pressure, while the position of splitters blades moves forward affects adversely the fan's performance. Sound Pressure Level (SPL) decreased with decreasing of size and forward positions of the splitters blades**.

Keywords: Centrifugal fan; Splitter blades; CFD; Noise reduction.

INTRODUCTION

Fan's designers are mainly aiming to increase the fan efficiency, so many different parameters which have great effect on the fan performance have been used. The most important parameters in fan design is the blade, which it represents the heart of any impeller. Many researches has been studied the influence of shape and blade number on the impeller performance [1-4]. In spite of increasing the number of impeller blades increases the head generated, they has negative effect on efficiency due to increasing in blockage [5], skin friction in the impeller passage and the impeller weight which increased input power.Using small number of blades causes high loading on blades [6], which may lead to material failure, low efficiency due to occurrence of flow separation [7] that generated at outlet of impeller especially with larger diameters. Therefore, to eliminate effect of flow separation, the idea of using splitter blades on the areas of the expected phenomena is raised.

The splitter blades are small additional blades place between the main blades of impeller to reduce the losses resulted from non-uniformity of flow and enhance fan performance. Madhwesh N, et al. used the splitter blades at different position on the leading and the trailing edges of the impeller, they found that the splitter blades placed at the impeller leading edge improved the recovery of fan the static pressure, while that placed at the trailing edge of the impeller has adversely affect on the static pressure recovery of the fan [8]. Man-Woong Heo, et al. have investigated influence of three parameters of the splitter blades geometry on the centrifugal fan performance, namely, the length ratio of splitter to main blade, the angular of the splitter with respect to the main blade, and the height ratio of outlet to inlet of the impeller. The results of the flow analysis shows reduction of flow separation due to using the impeller with splitter blades compare with the reference impeller; hence the fan performance has been enhanced [9]. Numerical simulation of splitter blades at various geometrical positions on impeller and diffuser has been studied by N. Yagnesh Sharma and K. Vasudeva Karanth. The analysis indicated that the splitter blades positioned at the diffuser exit improved the recovery of static pressure, while a marginal improvement in the static pressure recovery across the fan was found when splitter blades positioned at the mid-distance of the impeller blades trailing edge and diffuser leading edge, the splitters added at the trailing edge of the impeller suction side (at the quarter distance between the impeller main blades), adversely affected the static pressure recovery of the fan[10].

Abdul Nassar, et al. were studied the effect of tip clearance, splitter blades and its circumferential positions on performance of centrifugal compressor impeller. The study concluded that the tip clearance is lowering the pressure ratio and efficiency of the impeller and effect the impeller exit flow, using of splitter blades improved the mass flow as the inducer blockage area is reduced and the efficiency at off design condition, the optimum length ratio of splitter blade was found to be 0.5, while effect of the splitter blades position on pressure ratio and efficiency is negligible [11].

Wei Yang, et al. numerical and experimental study shows that using of the splitter blades improved hydraulic and cavitation performances of double suction centrifugal pump [6]. Influence of the splitter blades on the internal flow and performance of mini centrifugal pumps with the large blade angle at outlet are investigated[12], the experimental and numerical analysis of the mini pump shows improvement in the pump performance and flow condition at outlet of the impeller. The influences of number of the blades with and without splitter blades of different length on performance and energy saving of deep well pump were studied experimentally [13], as the number of blades are increased the pressure rise but it causes decreasing in pump efficiency. Negative effect on the pump performance resulted due to adding splitter blades to the impeller splitter blades to the impeller having the highest number of the main blades. Adding splitter blades to impeller having small number of blades gave increasing in efficiency with flow rate up to certain limit before decreasing depending on increasing of splitter blades. The study also showed that using of splitter blades led to energy saving up to 10%.

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Introducing splitter blades to small axial flow fan was studied numerically and experimentally, the results showed improvement in static characteristics of the fan with splitter blades through a certain range of flow rate, and also showed reduction in sound pressure level of fan in most frequency bands by comparing with original fan [14]. Wan-Ho Jeon has studied the impact of splitter blades on acoustic behaviour of centrifugal fan, the study found that the single splitter blades modified the acoustic behaviour of the impeller, while double splitter blades gave better acoustic behaviour than those of original impeller [15].
From above literatures survey can be concluded that the influence of splitter blades on noise and performance of a centrifugal fan has not been extensively studied. This paper aim to study the effects of splitter blades on fan performance and noise. Number of impellers with splitter blades having different size and position has been designed. Steady and transient flow simulation of the fan domain has been carried out. Fan performance and noise has been predicted using Ansys Fluent software capability.

GEOMETRY AND MESHING OF THE FAN MODEL

1.1 Geometry of the fan model

In this work, an industrial centrifugal fan of the type (9-19 No.4A) with 12 forward-curved blades is used to perform this numerical study. Table 1 shows the main characteristics of the fan impeller, while Table 2 shows the specifications of the fan impeller angles. Figure 1 shows the main components of the fan. To study the effect of splitter blades on fan performance and noise two modifications has been done to original impeller; firstly splitter blades having 0.25, 0.5 and 0.75 of the main blade length has been added to impeller at middle distance of each two neighbouring blades as shown in Figure 2, secondly the splitter blades angular positions have been changed by 7.5^{O} and 22.5^{O} from pressure side of the main blades as shown in Figure 3.

Table 1. Main characteristics of the fan impeller.

	part	Value (mm)
1	Inlet diameter	150
2	Out diameter	400
3	Plate thickness	3
4	Plate , Shroud diameters	450
5	Plate thickness	4
6	Shroud thickness	3

Table 2. Specifications of the fan impeller angles.

	part	Value (degree)
1	Inlet angle	30.98^{O}
2	Outlet angle	54.78 ^{O}

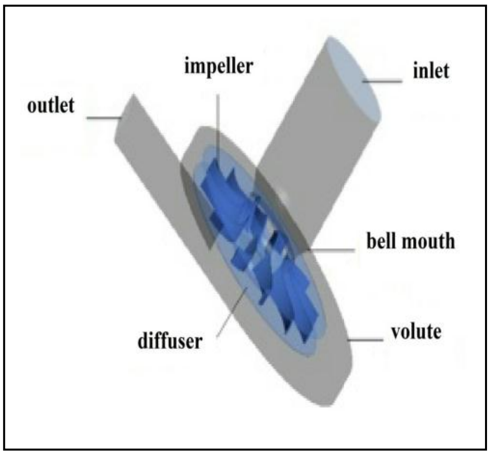

Figure 1. The main components of the original fan.

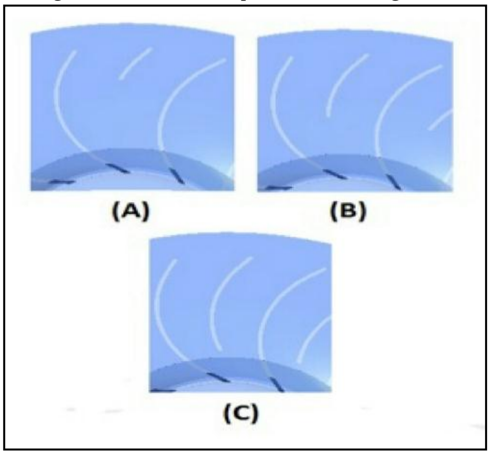

Figure 2. Length of the splitter blades at mid span (A) is 0.25, (B) is 0.5 and (C) is 0.75 of the main blade length.

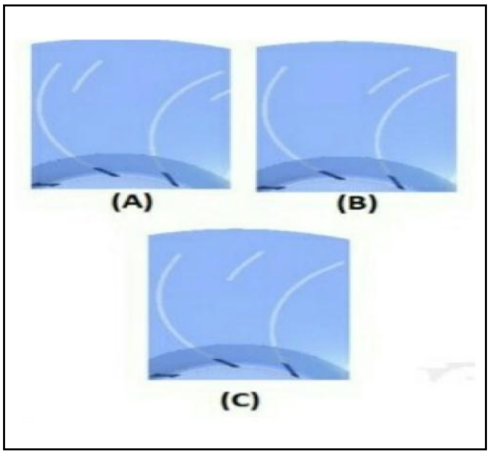

Figure 3. Splitter blades angular positions (A) at 7.5^{O}, (B) at 22.5^{O} from pressure side of the main blades, and (C) at mid span.

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1.2 Meshing of the fan model

ANSYS-ICEM CFD software is used to mesh the fan flow domain. The fan flow field consists of three domains inlet, impeller and volute. Because of using the sliding mesh concept, the three domains are meshed separately to create "grid interface" between separated domains. Since the fan parts geometry is complicated unstructured mesh for each part: inlet, volute and impeller has been done. And they had about 421 thousands of elements in the inlet zone, 1.9 million of elements in the impeller zone and 690 thousands in the volute zone. So the whole flow domain is formed of about 3 million unstructured elements. Figure 4 shows the mesh of three flow domains.

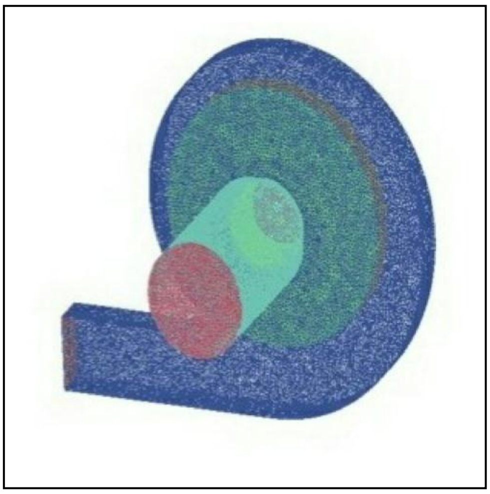

Figure 4. The mesh of the fan components.

CALCULATION OF NUMERICAL SOLUTION

1.3 Numerical technique

The complex flow field inside the entire centrifugal fan has been simulated using the commercial CFD software Fluent [16]. The three-dimensional motion of the air is considered to be the incompressible and steady flow, it calculated by using three-dimension Navier-Stokes equations. Because of turbulent state of the fluid the standard k−ε equation model is chosen as the turbulence model. The SEGREGATED implicit method, the pressure-velocity coupled using the SIMPLE calculation method are used in the numerical calculation of the flow, and turbulent kinetic energy, dissipation of turbulence and the momentum equation all are set to be second-order discrete upwind.

The impeller as a rotary motion zone is executed with the moving coordinate system. The fan efficiency is estimated by utilizing numerical calculation for all operating points on the entire performance curves.

The fan acoustic analysis is predicted by the sliding mesh technique, numerical simulation solved the unsteady flow to capture and calculate the instantaneous pressure fluctuation of the frequency domain. To improve the pressure fluctuation, the sound effect of the small eddies is modelled using Large Eddy Simulation.

1.4 Boundary conditions

The flow of the air through the fan is simulated by using suitable assumptions of boundary conditions:

The mass flow rate is set as boundary condition at the inlet, No-slip boundary condition is set for all solid surfaces of the fan, the rotating zones in turbo machines are usually numerically simulated via the moving reference frame (MRF) and the motion of the blades relative to the moving frame is set to be of zero value. For unsteady state of the flow the sliding mesh method is used to calculate the sound pressure for rotor-stator zone of interaction. The impeller turning speed is 1900rpm.

RESULTS AND DISCUSSION

In this study, the complete performance behaviour of a forward centrifugal fan at different operating points can be discussed by utilizing of the numerical simulations.

This approach deals with a forward centrifugal impeller in a comprehensive and detailed study, which can be supplemented the insufficiency of splitter blades effects in forward centrifugal impeller. The discussion the efficiency evaluation, torque estimation, flow visualization and noise spectrum analysis is explained as follow:

1.5 Efficiency Evaluation

In this study, the numerical simulation for the different impeller is studied via the computational fluid dynamics (CFD) Fluent software.

For demonstration purpose firstly, three models of splitter blades at middle distance of each neighbouring blades of the impeller are considered to evaluate the influences of splitter length on fan performance. Figure 5 and Figure 6 shows effect of the three splitter blades lengths, 0.25, 0.5 and 0.75 of the main blade length, the total and static pressures are increasing with increases of splitter length. The fan static and total efficiencies are decreasing with increasing of splitter blades length up to flow rate of 0.43 kg/s after that they are increasing with increases of splitter blades length. Figure 7 and Figure 8 shows fan performance curves of the efficiencies.

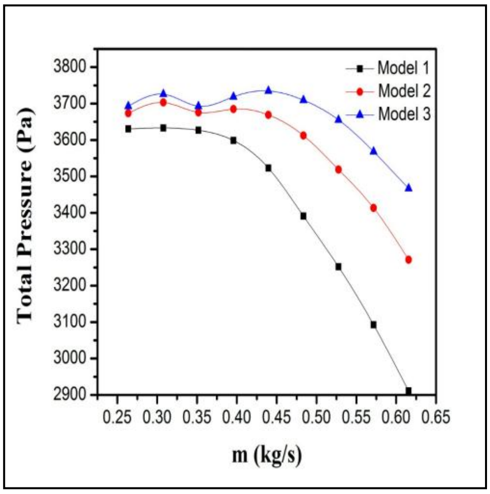

Figure 5. Total pressure vs. mass flow rate of the fan.

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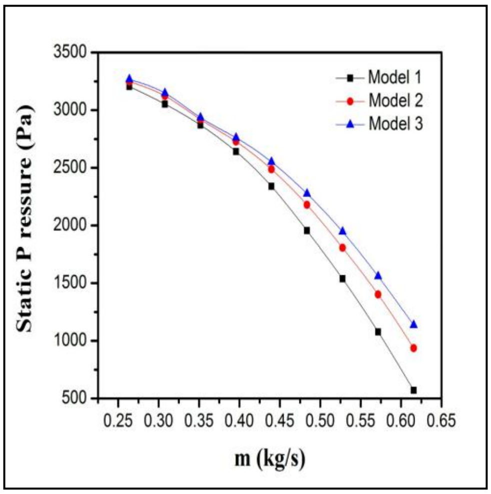

Figure 6. Static pressure vs. mass flow rate curves.

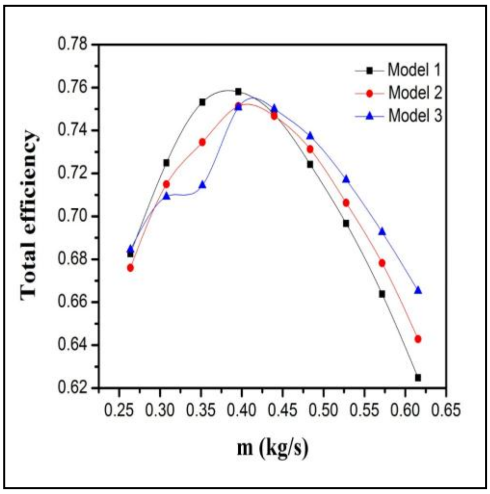

Figure 7. Total efficiency vs. mass flow rate curves.

The maximum total efficiency decreased with increasing of splitter blades length when compared with original impeller. The maximum decreasing in the total efficiency is about 4.2% and occurred at flow rate of 0.4kg/s.

Secondly, for the splitter blades added to original impeller at 7.5^{O} from pressure side of the main blade; Figure 9 and Figure 10 shows that the added splitter blades increased total and static pressures compared with the original fan while increasing of splitter length led to decrease the values of the pressures.

From Figure 11 it can be observed that the splitter blades generally decreased the total efficiency for the mass flow rate low the 0.44 kg/s and at the higher flow rate the splitter blades have adversely affect compared with the original blade. When the fan works at mass flow rate lower than 0.35 kg/s and higher than 0.48 kg/s, the increasing of splitter blades length increased the total efficiency. Figure 12 shows that the static efficiency is affected by the splitter blades, while the length of splitter has no effect especially at high flow rates. Figure 13 shows that the total and static pressures increasing when splitter blades is added and decreasing with increases of splitter blades length.

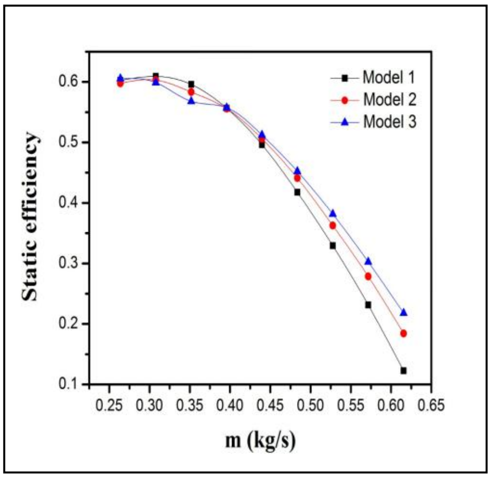

Figure 8. Static efficiency vs. mass flow rate curves.

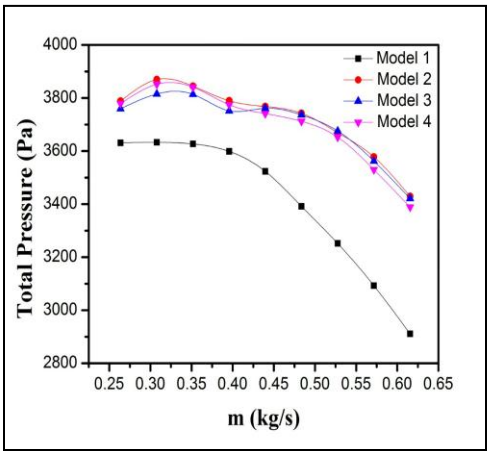

Figure 9. total pressure vs. mass flow rate curves.

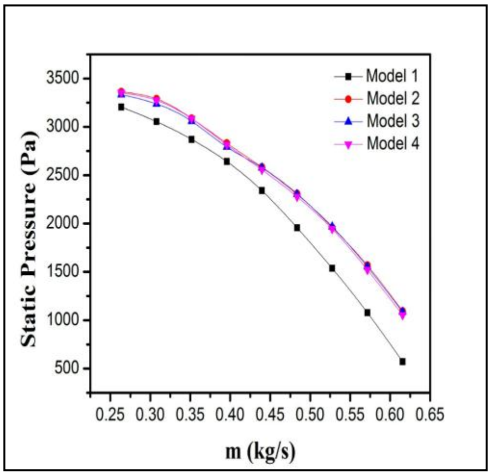

Figure 10. Static pressure vs. mass flow rate curves.

Thirdly, for the splitter blades added to original impeller at 22.5^{O} from pressure side of the main blade; Figure 13 and Figure 14 shows that the increasing of splitter blades length increased total and static pressures compared with the original fan, while increasing of pressures has higher value at high flow rates. Figure 15 and figure 16 it can be observed that increasing of splitter blade length shows decreasing in both total and static efficiencies at low flow rates, while at high flow rates shows adversely effects.

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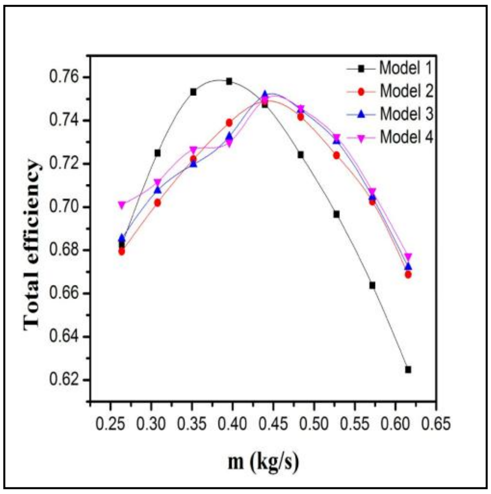

Figure 11. Total efficiency vs. mass flow rate curves.

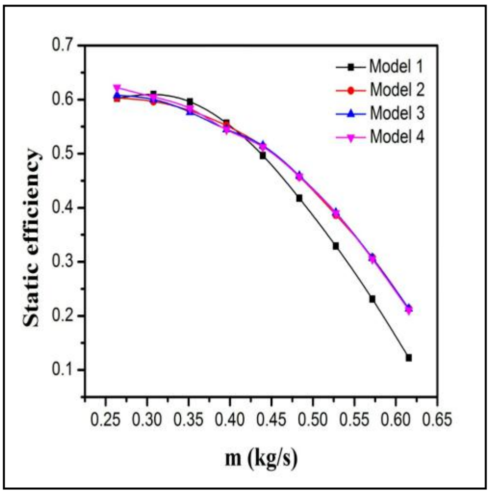

Figure 12. Static efficiency vs. mass flow rate curves.

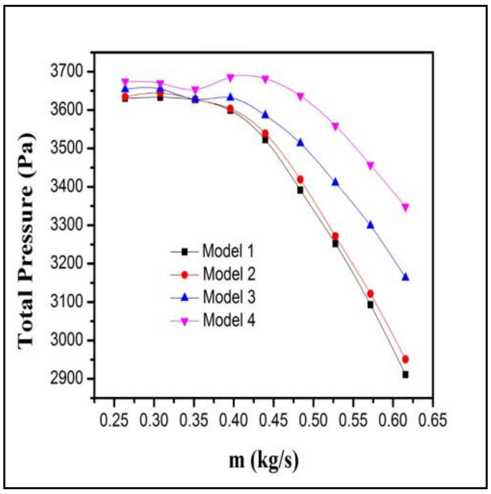

Figure 13. Total pressure vs. mass flow rate curves.

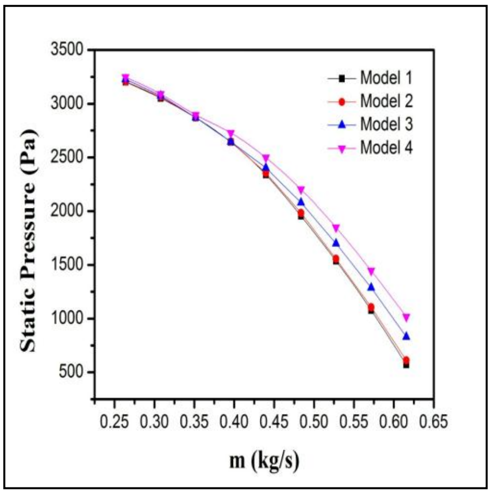

Figure 14. Static pressure vs. mass flow rate curves.

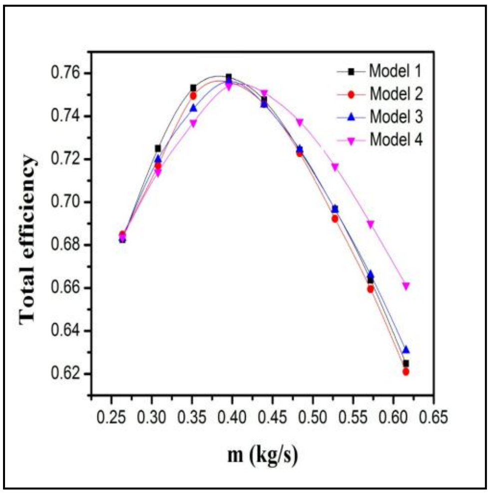

Figure 15. Total efficiency vs. mass flow rate curves.

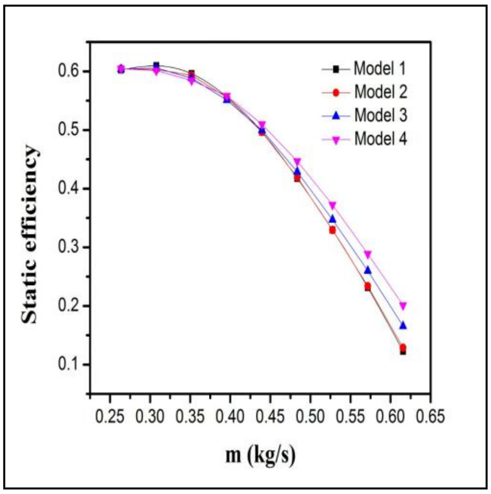

Figure 16. Static efficiency vs. mass flow rate curves.

1.6 Torque Estimation

In this is paper, the torque has estimated at various mass flow rates, splitter blades length and positions are calculated via computational fluid dynamics (CFD) simulation and plotted in Figure 17, Figure 18 and figure 19.

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1.7 The torque enlarges with an increasing mass flow rate and reaches its maximum value at the free-delivery condition. Also it can be noticed that at mid spam and 22.5^{O} positions the torque increasing with increases of splitter blades length, while it increasing with increases of splitter blades length at 7.5^{O} position.

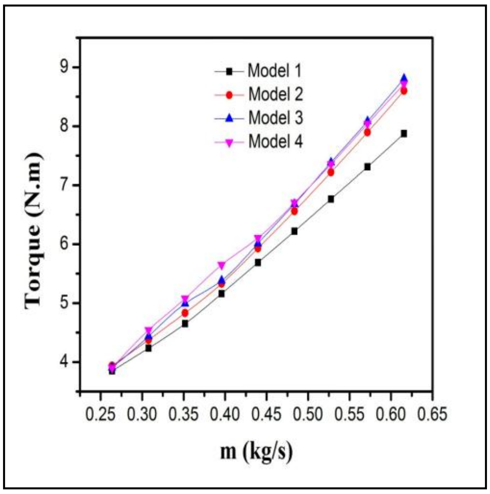

Figure 17 Torque at middle distance vs. mass flow rate curves.

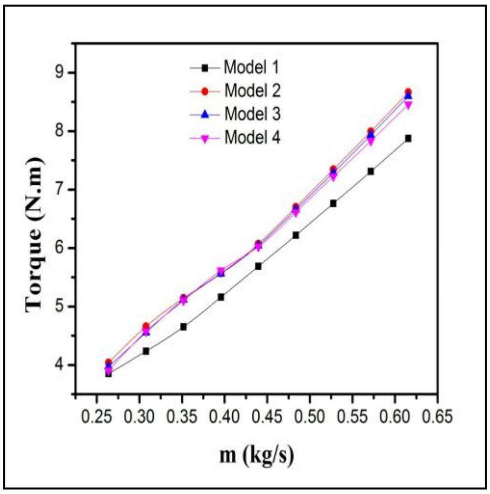

Figure 18. Torque at back position vs. mass flow rate curves.

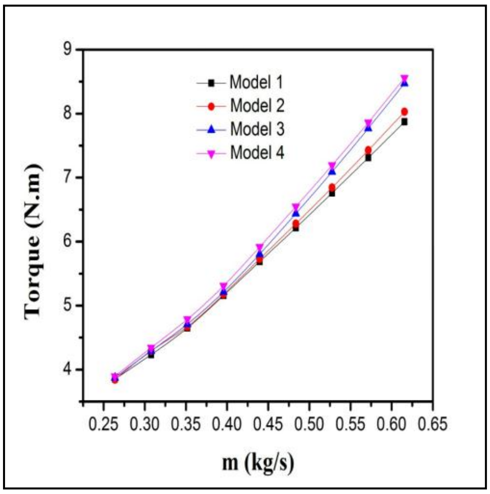

Figure 19. Torque at forward position vs. mass flow rate curves.

1.8 Flow Visualization

Besides the pressures and efficiencies curves, this study presented the effects of splitter blades positions and lengths on internal flow of the impeller. Figure 20 shows that the vortex flow regions at side suction side of the main blades are improved when splitter blades has been added at mid spam, increasing of splitter blades length gave better improvement .

The splitter blades at position of 7.5^{O} from pressure side of the main blades show a little improvement vortex region with the splitter blades length increasing but of splitter blades length 0.75 shows increases in vortex region Figure 21. Adding splitter blades at position of 22.5^{O} from the main blades pressure side improved the flow near the main blades suction, otherwise the vortex region is shift to suction side of splitter blades and it increases with increasing of splitter blades length Figure22.

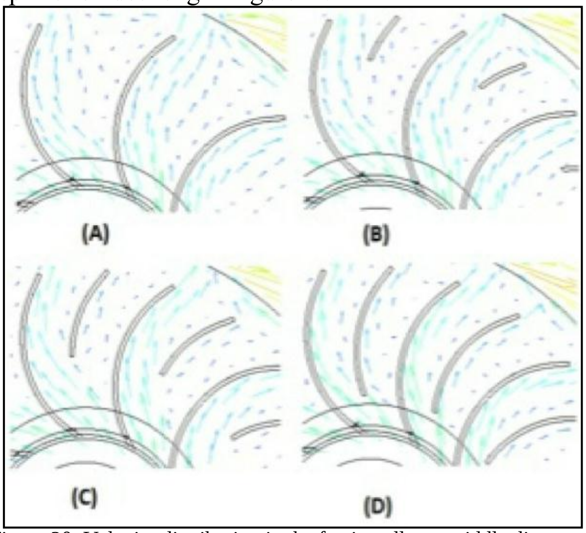

Figure 20. Velocity distribution in the fan impeller at middle distance.

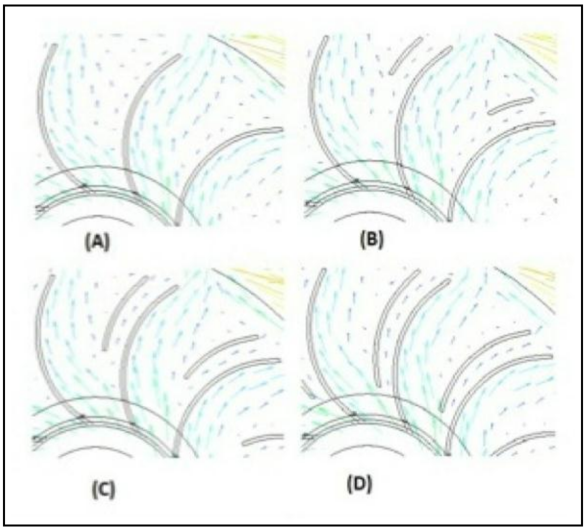

Figure 21. Velocity distribution in the fan impeller at the back ward.

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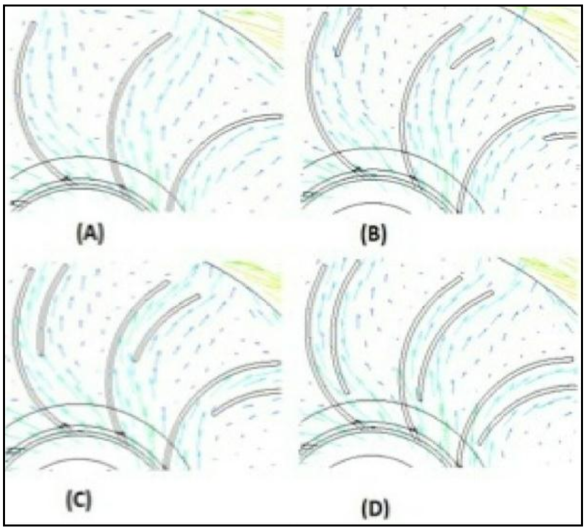

Figure 22. Velocity distribution in the fan impeller at the forward.

1.9 Acoustic Noise Evaluation

In this study, the noise frequency spectrum at the fan outlet is calculated via CFD codes. In numerical simulation, the acoustic receiver is placed at 1m with 45^{O} from axis of rotation. The splitter blades at the back position decreased the noise with increasing of the splitter blades length Figure 23.

The middle position showed decreasing in noise with increasing of the splitter blades length Figure 24. While the forward position of splitter blades shows decreasing in noise with increasing of splitter blades length till half length splitter blades Figure 25. Referring to Figure 26 it has been noticed the forward positions enhancing the decreases of noise.

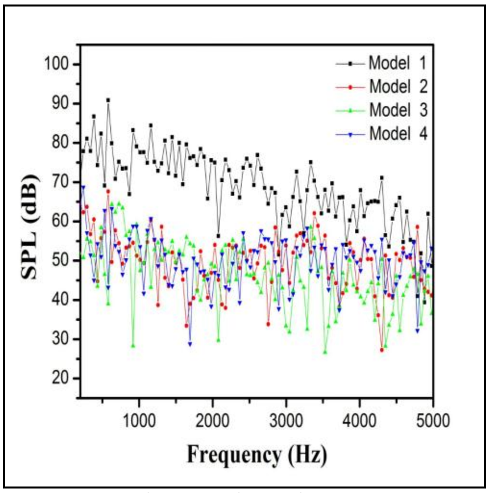

Figure 23. SPL vs. frequency for the fan at backward position.

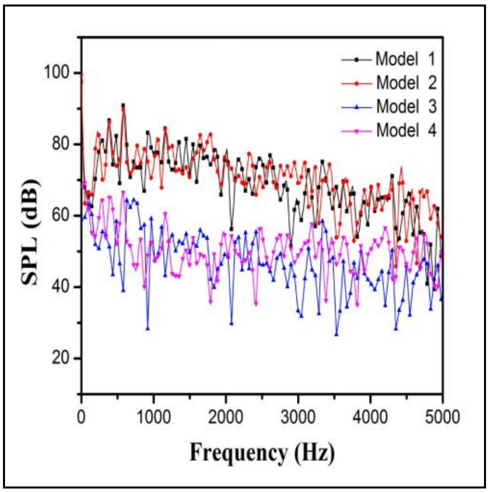

Figure 24. SPL vs. frequency for the fan at middle distance position.

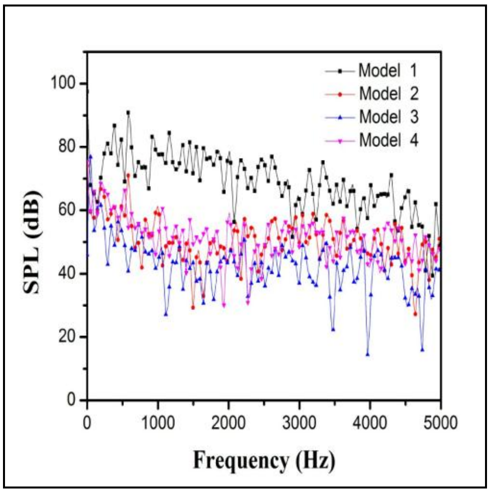

Figure 25. SPL vs. frequency for the fan at forward position.

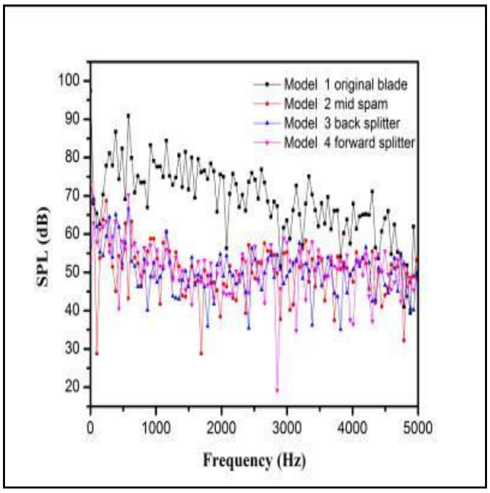

Figure 26. SPL vs. frequency for the fan to the forward positions.

CONCLUSION

In this paper, a comprehensive performance analysis for forward centrifugal fan with impeller having splitter blades of different size and positions is carried out through numerical approach. The numerical visualization of internal flow characteristics is very important for fan design. Moreover, by the calculation of pressure, torque and efficiency, the aerodynamic performance of fan is estimated in detail at each operating point. Furthermore the aerodynamic noise is achieved through numerical simulations.

The simulation results indicate that adding splitters in different size and position improved flow field. Increasing size of splitters increase efficiency and pressure, while the position of splitters moves forward effects adversely the fan's performance. Sound Pressure Level (SPL) decreases with decreasing of size to some extend and forward positions of the splitters.

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REFERENCES

[1] Yan, G., Dilin, P., and Lixiang, Z., Parameterized Design of Centrifugal Fan's Impeller, International Conference on Measuring Technology and Mechatronics Automation, Changsha, China, March 2010, pp. 872–875.

[2] Hassenpflug, W.C., The incompressible two-dimensional potential flow through blades of a rotating radial impeller, Mathematical and Computer Modelling, 2010, 52,(9), pp. 1299–1389.

[3] Gölcü, M., Usta, N., and Pancar, Y., Effects of Splitter Blades on Deep Well Pump Performance, Journal of Energy Resources Technology, 2007, 129,(3), pp. 169–176.

[4] Singh, O.P., Khilwani, R., Sreenivasulu, T., and Kannan, M., Parametric Study of Centrifugal Fan Study Performance: Experiments and Numerical Simulation, International Journal of Advances in Engineering and Technology, 2011, 1,(2), pp. 33–50.

[5] Pranit, M. P., and Todkar, R.G., An Overview of Effect of Splitter Blades on Centrifugal Pump Performance, International Journal of Engineering Research and Technology, 2013, 2,(1), pp. 2249–2252.

[6] Wei Y., Xiao, R., Wang, F., and Wu, Y., Influence of Splitter Blades on the Cavitation Performance of a Double Suction Centrifugal Pump, Advances in Mechanical Engineering, 2014, volume 2014, pp.1–9.

[7] Gölcü, M., Neural network analysis of head-flow curves in deep well pumps, Energy Conversion and Management, 2006, 47,(7), pp. 992–1003.

[8] Madhwesh N., Karanth, K.V., and Sharma, N.Y., Member, IAENG, Impeller Treatment for a Centrifugal Fan using Splitter Vanes – A CFD Approach. Proceedings of the World Congress on Engineering, London, U.K. July 2011, pp. 1981 – 1986.

[9] Heo, M.W., Kim, J.H., Cha, K.H., and Kim, K.Y., Parametric Study on Aerodynamics Performance of a Centrifugal Fan with Additionally Installed Splitter Blades, Proceedings of the ASME Fluids Engineering Division Summer Meeting, Incline Village, Nevada, USA, July 2013, pp.1– 6.

[10] Sharma, N.Y., and Karanth, K.V., Numerical Analysis of a Centrifugal Fan for Improved Performance using Splitter Vanes. World Academy of Science, Engineering and Technology, 2009, 3,(12), pp. 414– 420.

[11] Abdul Nassar , Nagpurwala, Q., and Reddy, K.B., Design and CFD investigation of Centrifugal Compressor for Turbocharger and Parametric Study of Splitter Blades, SASTech–Technical Journal, 2006, 5,(2),pp.35– 41.

[12] Shigemitsu, T., Fukutomi, J., Kaji, K., and Wada, T., Unsteady Internal Flow Conditions of Mini-Centrifugal Pump with Splitter Blades, Journal of Thermal Science, 2013, 22,(1), pp. 86–91.

[13] Gölcü, M., Pancar, Y., and Sekmen, Y., Energy saving in a deep well pump with splitter blade. Energy Conversion and Management, 2006, 47,(5), pp. 638–651.

[14] Zhu, L., Jin, Y., Li, Y., Jin, Y., Wang, Y., and Zhang, L., Numerical and experimental study on aerodynamic performance of small axial flow fan with splitter blades. Journal of Thermal Science, 2013, 22,(4), pp. 333–339.

[15] Jeon, W.H., A numerical Study on the Acoustic Characteristics of a Centrifugal Impeller with a Splitter, GESTS Int'l Trans. Computer Science and Engr., 2005, 20,(1), pp. 17–28.

[16] Fluent 6.3 documentation, FLUENT INC.