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Experimental Investigation on Design Enhancement of Axial Fan Using Fixed Guide Vane

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Abstract: Airflow passes through the rotating blade in an axial flow fan will experience a helical flow pattern. This swirling effect leads the system to experience swirl energy losses or pressure drop yet reducing the total efficiency of the fan system. A robust tool to encounter this air spin past the blade is by introducing guide vane to the system. Owing to its importance, a new approach in designing outlet guide vane design for a commercial usage 1250mm diameter axial fan with a 30° pitch angle impeller has been introduced in this paper. A single line metal of proper curvature guide vane design technique has been adopted for this study. By choosing fan total efficiency as a target variable to be improved, the total and static pressure on the design point were set to be constraints. Therefore, the guide vane design was done based on the improvement target on the static pressure in system. The research shows that, with the improvement in static pressure by 29.63% through guide vane installation, the total fan efficiency is increased by 5.12%, thus reduces the fan power by 5.32%. Good agreement were found, that when the fan total efficiency increases, the power consumption of the fan is reduced. Therefore, this new approach of guide vane design can be applied to improve axial fan performance.

1. Introduction

Fans

are widely used in industrial and commercial applications such as ventilation, material handling, boilers, refrigeration, dust collection, cooling applications and others. In industrial applications fans are commonly used to supply ventilation or combustion air, to circulated air or other gases through equipment and to exhaust air or other vapors from equipment. There are two primary fans that are centrifugal and axial fan. Centrifugal fans moves the air radically outwards by centrifugal action, and then tangentially away from the blade tips. This type of fans are normally known as blowers and suitable for harsh operating condition, such as system with high temperatures, moist and material handling. Where else, the axial flow fan drives the air through the impeller in approximation of an axial direction. Axial fans utilize blades that force air to move parallel to the shaft about which the blades rotate, hence the

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name. Owing to its cost effectiveness and multi-functional nature, the axial fan has been widely adopted in the industrial, commercial, consumer, institutional, and residential applications. ^{[13], [15]}

Many development and researches have been carried out in optimizing the design, application and efficiency improvement of the fan. The experimental investigation and numerical modeling techniques have been widely used to develop and optimize the fan ^{[1], [2]}. Initially, researches have been carried out on the design and optimization of the rotating impeller, such as investigation on the effect of installation angle of rotor blade, forward-skewed blade effects, aerofoil filled or aerodynamic effects on blade cross section and etc. In reference ^[1] the downstream flow resistance method has been developed for predicting the fan performance and the stalling effect in a fan system. Besides that, study on effects of installing angle setting for the rotor blade was explored in reference ^[2] on a axial flow fan and ^[4] on wells turbine, prior to improve the overall efficiency of the system. Apart from impeller design, investigation such as inlet flow distortions effect, tip clearance losses estimation, noise improvement, and swirl energy losses also have been demonstrated in references ^{[5], [8]} and ^[9]. Other than designs, research have been carried on the system or method development such as, an optimization technique based on the gradient method by reference ^[6] and ^[7], modification on the mining exhaust fan in reducing the 'Air Stray Losses' prior to reduce the electric consumption to overcome the situation by ^[10]. From the available published literatures as mentioned, there were less works have been reported on the guide vane design and application effect in improving axial fan performance. A paper by T.Setoguchi et.al. ^[3], presented the guide vane on the both inlet and outlet side of the rotor in overcoming the lower efficient and poor starting characteristic of the wells turbine. And in another paper by YE Zeng-Ming et.al. ^[6] has introduced straighter vanes onto a large generator in overcoming, thus changing the swirl energy losses into useful energy in improving the efficiency of the system.

However, there is still room for improvement for guide vane design onto commercial usage axial fan to be explored. Therefore, an investigation on new approach in designing a fixed guide vane for a 1250mm diameter axial fan and its effect on improving total fan efficiency were demonstrated in this paper. An appropriate guide vane design can improve the airflow in a fan system by reducing swirling and get a higher efficiency, thus reducing the power consumption of the system. So, in this study, the fixed vane was design by choosing static pressure as a target variable to be maximized in the fan system, prior to improve the overall fan efficiency.

2. Experimental Apparatus

The experiment was conducted on a Type D test rig setup referred to AMCA 210-07 (Air Movement and Control Association, Inc.) ^[12] Standard with ducted inlet and outlet schematically shown in Figure 1. The inlet duct has a cross sectional area of 4.9 m² and a length of 5 m. An expansion connects the inlet duct and the test chamber which has a 64.2 m² cross sectional area and an equivalent length of 10 m. The downstream end of the test chamber on the other hand is connected to an outlet duct with a cross sectional area identical to the inlet duct with a length of 3.75 m through a gradual contraction. The fan is located at the inlet duct where at the upstream of the fan host an inlet bell and the transition allows the air to smoothly accelerate from a static condition to a high speed flow. In this study, a 12 profile rotor blade of 1250mm diameter, 30° pitch angle axial fan with a hub to tip ratio of 0.28 and 7 mm tip clearance selected (figure 2). Additionally, a 13 profile fixed vane is designed to compare and improve the fan performance.

The study was conducted using an approach termed as “downstream flow resistance” method or DFR for short to analyze the performance of the axial fan. DFR method is an approach that uses flow resistance that exist in a fan system to gain access to the fan performance where the pressure rise before the flow resistance and the pressure drop across the resistance region are used for the purpose of computing the static pressure and flow rate respectively. ^[1] It is possible to perform an uncertainty analysis to identify a range of values within which the true value might lie. Therefore, AMCA 210 chose an acceptable probability of 95%. According to AMCA standards, the uncertainties in the experimental results can be expressed in two parts, the measurement and combined uncertainties.

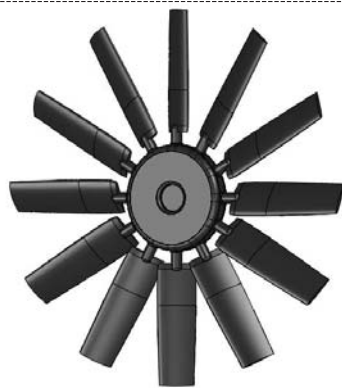
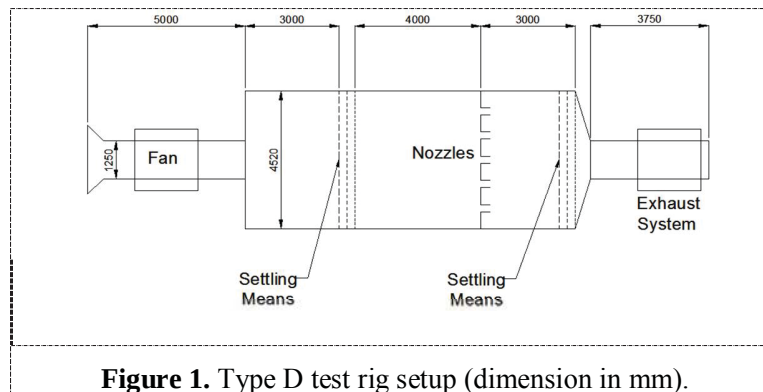


Figure 2. Rotor blade (outer diameter 1250mm).

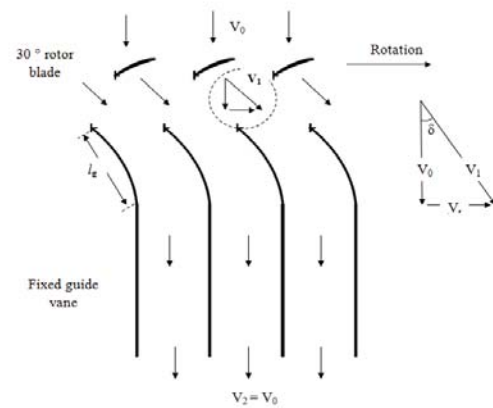


Figure 3. Guide vane schematic diagram.

2.1. Calculation

The fan total pressure was calculated from measurements of the pressures in ducts or chambers, corrected for pressure losses that occur in the measuring duct between the fan and the plane of measurement. A derivation of this calculation is Eq. 1. The fan static pressure was calculated from Eq. 2 ^[14].

$P_t = P_{s7} + P_v$ (1)	$P_s = P_t - P_v$ (2)
$H = \frac{2\pi TN}{60}$ (3)	$\eta_t = \frac{QP_t K_p}{H} \times 100\%$ (4)
$\eta_s = \eta_t \left(\frac{P_s}{P_t} \right)$ (5)	

As a torsion element is used to measure torque, the fan power input is calculated from the torque and the fan rotational speed using Eq. 3^[14]. The fan total efficiency is the ratio of the fan power output to fan power input, as shown in Eq. 4. With the derivation of total efficiency, the static efficiency was calculated using Eq. 5^[14].

3. Design of guide vane

There were two type of guide vane can be provided to an axial fan to reduce the rotational energy losses. It can be located either on the outlet side called as outlet guide vane or on the inlet side called as inlet guide vane. The outlet guide vane produce static pressure partially to the system, where else the inlet guide vane will prepare the airflow for the blades. Since in this study, static pressure becomes the target objective to improve the fan efficiency, therefore the outlet guide vane would be the best choice. Figure 3 shows the 2D schematic diagram of the fixed vane design respective to the 30° rotating impeller.

The guide vane with a chord length of $l_g = 300\text{mm}$, and the end of the curvature is extended to 600mm for the purpose of effective airflow correction and to utilize the motor place as a hub for the guide vane. Good agreement found that the longer the straightener vane, the better airflow correction can be achieved.

^[6] The leading angle, δ of the guide vane is calculated from Eq.6^[14],

$\tan \delta = \frac{V_r}{V_a}$ (6)	$V_a = \frac{cfm}{A_a}$ (7)
$V_r = \frac{233 \times 10^6}{rpm} \times \frac{SP}{r}$ (8)	$A_a = \frac{(D^2 - d^2)\pi}{576}$ (8)

Where V_a , is the axial air velocity in feet per minute through the annulus by Eq.7 and the V_r is the rotational component in feet per minute of the helical air velocity past the blades by Eq.8. And the Annular area in square feet if D and d are in inches, given by Eq.9^[14]. It may be noted here that, determination on the static pressure on the guide vane design equation will be discuss future in section 4.0 (results and discussion). Therefore, based on this calculation the angle of fixed guide vane is set to be 40° with a constant thickness of 3 mm.

4. Results and Discussion.

In this section, results comparison has been made between without and with guide vane application for the 1250mm, 30° angle rotor blade axial fan. Figure 5 shows the efficiency and static pressure vs. volume airflow graph for the application of without guide vane. The highest efficiency for the without guide vane application is 64.96% with static pressure of 300Pa for the flow rate, Q of 15.986 m³/s. (optimum point shown in figure 4)

From the Eq.4 (section 2), it is found that the improvement in static pressure in fan system will contribute to the overall fan efficiency to be increase, thus reduces the power consumption of the fan. Therefore, in this study the highest point of the static pressure, 351Pa in the fan operation curve region was selected to be improved with the guide vane application onto the system. Based on this selected target in static pressure, the guide vane angle was calculated in section 3. The selections point the static pressure improvement in shown in figure 5. From the application of the fixed guide vane, the static pressure were improvement approximately to 29.63% from the without guide vane application. The comparison and the improvement region in static pressure graph for with and without guide vane application is shown in figure 5.

By comparing the results at approximately at the same flow rate, Q , found that the total efficiency is increase by 5.12% at the static pressure of 304Pa for the application of with guide vane. Therefore the optimum efficiency for the guide vane application onto 1250mm axial fan would be 70.08% as shown in figure 6. Good agreement found that, the improvement in the total fan efficiency were obtained approximately at the same flow rate and static pressure value on the both cases of with and with guide vane application. This shows that, the energy losses in the system have been recovered by the guide vane installation to the fan system without any additional energy requirement. Thus, by increase in the total efficiency, the total power consumption of the fan have been reduce by 5.32% from the without guide vane application. Figure 7 shows the comparison of the power consumption for with and without guide vane application.

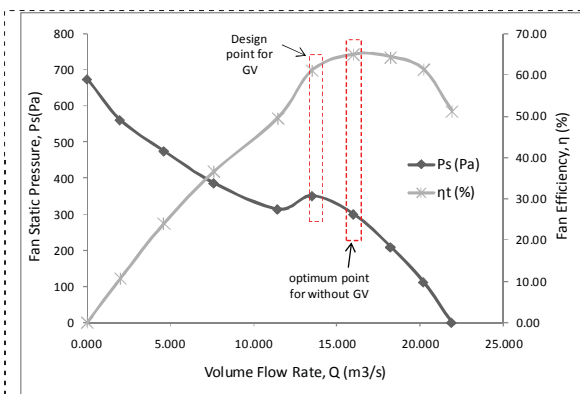


Figure 4. Efficiency and static pressure curve for without guide vane application.

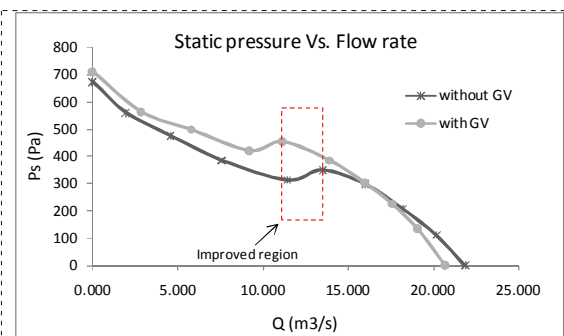


Figure 5. Static pressure vs. flowrate for with and without guide vane application.

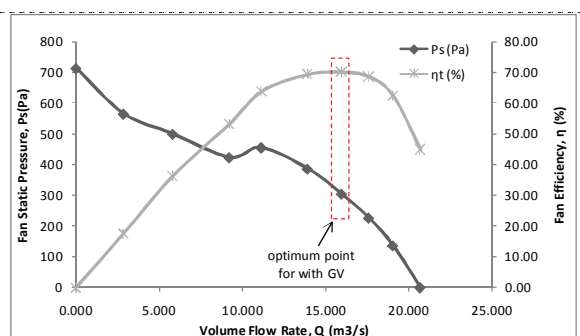


Figure 6. Efficiency and static pressure curve for with guide vane application.

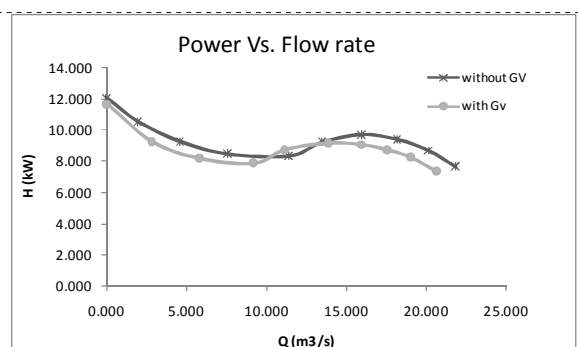


Figure 7. Power consumption comparison graph.

5.0 Conclusion

From the study, found that guide vane application onto axial fans would be one of the suitable solutions prior to encounter the air swirling or losses occur in a fan system. Reducing the swirl energy losses in a fan system can improve the total efficiency of the system. In this paper, 40° fixed guide vanes were designed onto 30° angle blade 1250mm axial fan. The single line proper curvature guide vane designing method was adopted with static pressure as a target objective in this study. From the comparison of the experimental results in section 4, found that the improvement in the static pressure for a fan system, increases the total fan efficiency of the system thus reduces the power consumption of the fan at the same time.

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