

Reduction of motor fan noise using jute composites

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This study presents fabrication methodology of two redesigned fans for noise reduction and improving cooling performance of baseline fan (original configuration fan). These two redesigned fans (Fan-1 and Fan-2) are fabricated using glass and jute fiber in propylene glycol resin by hand lay-up technique.

Keywords: Glass fibre, Jute fibre, Motor fan, Noise, Semi-anechoic chamber

Introduction

Motor-fans used for cooling electric motors have long been recognized as one of the major noise sources. Noise of axial flow fan mainly consists of vibration-induced and aeroacoustic noise. Wkim & Chung¹ presented reduction of acoustic noise generated by electromagnetic forces in an induction motor. Alon *et al*² implemented active noise control systems to axial fans, and achieved a sound power level active reduction of 7.8 dB, in addition to 3.3 dB of passive reduction. Dipa Ray *et al*³ observed that an interlayer helped to improve the damping capacity of jute reinforced composites, with a lowering in stiffness values. Lee *et al*⁴ proposed a low noise design for centrifugal fan in a household refrigerator. Seung Heo *et al*⁵ developed low noise centrifugal fans by modifying linear trailing edge lines of fan blades into inclined S-shaped lines. Overall noise from new fan is reduced by 2.2 dB in comparison with that from existing fan in refrigerator. Tandon⁶ suggested that vibration control, barriers and enclosures can be used for noise control and should be considered at the design stage. Paul *et al*⁷ investigated the mechanical properties of sisal, hemp, coir, kenaf and jute reinforced polypropylene composites processed by compression molding using a film stacking method. Andra *et al*⁸ presented an experimental study on influence of some geometric features on aeroacoustic behavior of a squirrel-cage fan, used in automotive air conditioning units. Thus a lot of work has been done on noise reduction of blowers

and HVAC (heating ventilation and air-conditioning) fans but less research has been conducted on motor fan cooling performance and noise reduction using natural composites.

This study presents application of two redesigned fans, fabricated using glass and jute fiber, for replacing plastic material of baseline fan for vibration noise reduction and improving cooling performance of baseline fan without changing fan operating point.

Experimental Section

Reinforced Composites

Reinforced composites used were glass and jute fiber. Jute is one of the cheapest and strongest of all natural fibers. Although tensile strength and Young's modulus of jute are lower than those of glass fibers, specific modulus of jute fiber is superior to that of glass and on a modulus per cost basis, jute is far superior. Specific strength per unit cost of jute, too, approaches that of glass. Therefore, jute fiber can be a very potential candidate in making composites, especially for partial replacement of high-cost glass fibers for low load bearing applications. Incorporation of glass with jute brings about large increases in mechanical properties of composites.

Baseline Fan

Baseline fan (original configuration motor fan: external diam, 234.0 mm; and hub diam, 40.0 mm) is an axial flow plastic fan (shroud thickness, 2.5 mm; and angular speed, 2920 rpm), which consists of 10 numbers of evenly spaced straight radial blades of constant cross-section and it is driven by 20 HP (14.71 KW) induction

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Table 1—Baseline fan and redesigned fans specifications

Parameters	Baseline fan	Fan-1	Fan-2
No. of blades	10	7	7
Type of flow	Axial	Mixed	Mixed
Blade shape	Straight	Backward-skewed (20°)	Backward- skewed (20°)
Blade profile	Rectangular	NACA 65-010	NACA 65-010
Blade spacing	Equal	Equal	Equal
Blade spacing (°)	36.00	51.43	51.43
Fan material	Plastic (nylon)	Glass fiber (wt 35%)	Jute fiber (wt 25%) + Glass fiber (wt 12%)

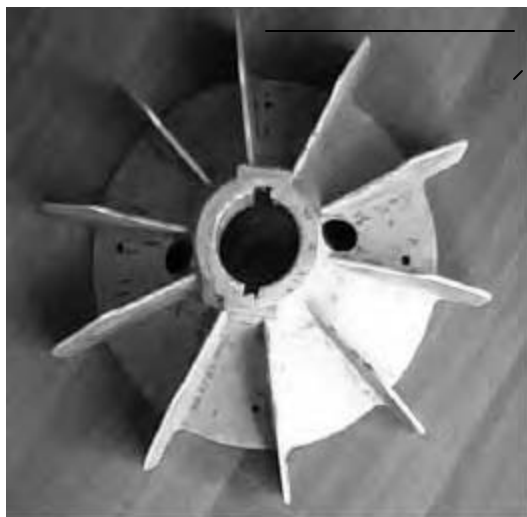


Fig. 1—Baseline fan

electric motor (Fig. 1, Table 1). As the fan in this application rotates at single constant speed, investigation is done at only one operating point, which corresponds to the flow resistance caused by electric motor surface having cooling ribs. Operating point corresponds approximately to the best efficiency point.

Characteristics of Redesigned Fans

Fan-1

Fan-1 was designed with 7 backward inclined blades (Fig. 2a, Table 1) having NACA (National Advisory Committee for Aeronautics) 65-010 airfoil and constant cross section. Inner shroud (IS) and outer shroud (OS) provide an inlet bell mouth shape. Thickness of IS (4.0 mm) is more than that of OS (3.0 mm) because pressure force is more at IS than OS, which is nearer to center of rotation. OS provides bell mouth entry to reduce noise. Other parameters are as follows: angular speed, 2920 rpm; external diam, 233.0 mm; and hub diam, 43.0 mm. Fan-1 is fabricated by hand lay-up method with E-glass fiber (wt 35%) and propylene glycol resin matrix. E-glass chopped mat (0/90 & 0/0 symmetric lay-ups)



a)



b)

Fig. 2—Redesigned fans: a) Fan-1; and b) Fan-2

were selected for fabrication of IS (9 layers), OS (7 layers) and blade.

Fan-2

Fan-2 consists of 7 backward inclined blades (Fig. 2b, Table 1), NACA 65-010 airfoil, constant cross section and even blade spacing. It has following parameters: angular speed, 2920 rpm; external diam, 233.0 mm; hub diam, 43.0 mm; IS thickness, 3.0 mm; and OS thickness, 2.0 mm. Jute fiber (wt 25%), E-glass fiber (wt 12%) and propylene glycol resin matrix were

used for fabrication by hand lay-up method. Jute and E-glass chopped mat (0/90 & 0/0 symmetric lay ups) were selected for fabrication of IS (5 layers) and OS (3 layers) to reduce the cost and weight of fan. Number of lay ups are selected to maintain required thickness based on the thickness of each layer. Glass fiber was used for inner and outer layers of all parts. Jute fiber was sandwiched between glass fiber layers.

For composite applications having good bonding between fiber and resin matrix, jute was treated with alkali as mercerization process. Jute fibers were cut to 50 cm of length and immersed in a 5% NaOH solution for 4 h at 30°C maintaining a liquor ratio of 15: 1. Fibers were then washed several times with fresh water to remove any NaOH sticking to fiber surface, neutralized with dilute acetic acid and finally washed again with distilled water. Fibers then dried at room temperature (RT) for 48 h followed by oven drying at 100°C for 6 h, and then used in fabrication of Fan-2. For all fabrications, E-glass fibers (density, 2560 kg/m³; and modulus, 72.35 GPa) and jute fibers (density, 1360 kg/m³; and modulus, 14.69 GPa) were used as reinforcing material in propylene glycol resin [Ecomolon product (grade, 4473; density, 1210 kg/m³; and modulus, 2.5x10⁻⁴ MPa)]. Matrix material, resin was mixed with 1% each of accelerator (cobalt naphthalene), promoter (N–N dimethyl aniline) and catalyst [Methyl ethyl ketone peroxide (MEKP)].

Fabrication of Redesigned Fans

Pattern Preparation for Inner Shroud (IS), Outer Shroud (OS) and Blades

Teak wood patterns were prepared as per sketch for IS, OS and blades. Hand lay-up technique was used for fabrication of all redesigned fans. For IS and OS, wooden material was shaped into required pattern by turning operation on lathe machine. Templates of required shapes were made, and using these templates, required curvatures of inner surfaces of the patterns of shrouds are machined. Surface finishing was done using emery paper during turning operation. Patterns for both the shrouds were manufactured. Using wooden material, blades (½ m long) of required aerofoil shape were made. To wooden blades, required chemicals (releasing agent, mixture of catalyst, accelerator, resin and pigment) were applied on surface, and then dried for 2 h. After completely drying, layers of glass fiber and mixture of catalyst, accelerator, resin and pigment were applied on the surface one after the other. Then blades were dried for 24 h. Mold on the surface is slowly removed and thus

upper part of the pattern made. Same procedure is followed for lower part of the pattern.

Fabrication of Inner Shroud (IS) and Outer Shroud (OS)

Releasing agent is applied on inner surfaces of patterns and then dried for few minutes. Resin is mixed with 1% each of accelerator, promoter and catalyst. After drying, mixture of catalyst, accelerator, resin and pigment is applied on inner surfaces in a fine layer and it is dried for 2 h. Glass and jute fibers are cut into small pieces of required shape. After surface layer gets completely dried, layer of glass fiber is placed on the surface of pattern. Resin is added to fibers using brush. Jute fibers are sandwiched between glass fibers. Following the same process, layers are placed on both upper and lower parts of the pattern. Same hand lay up technique is used for fabrication of IS, OS and blades.

Assembling the Parts

Inner circumferential areas of both shrouds were divided into 7 divisions. Lines inclined at 20° to 7 divisions were marked on the surfaces. Aerofoil shaped grooves were made on the surface of IS to fix blades to IS using epoxy (araldite) and then dried for 1 h. Final fabricated redesigned fans were cured for 48 h at RT. Metal tapered sleeves are then prepared and inserted into hubs of redesigned fans to be assembled with motor shaft.

Dynamic Balancing of Redesigned Fans

After fabrication and sleeves preparation, dynamic balancing was done at Marin Corporation of India, Visakhapatnam, India for two redesigned fans to minimize unbalanced forces. Balancing is done by adding weights to the rotor. Dynamic balancing was done as follows: i) Shaft was coupled to fan, fixed in between the chucks of machine and then made to rotate at certain speed; ii) Unbalanced forces were minimized by adding masses as per the results obtained from dynamic balancing of redesigned fans; and iii) For Fan-2, unbalanced forces were minimized by adding masses 0.72 g and 7.9 g in 60° plane and 30° plane at radius of 210.0 mm respectively. Now all unbalanced masses were well below the acceptable level (0.15 g).

Results and Discussion

Experimental Study in Semi-Anechoic Chamber

For this experiment, narrowband sound pressure levels (SPL) are measured by Bruel and Kjaer 4160 condenser microphone and frequency analyzer (Pulse). All SPLs measurements were performed in semi-

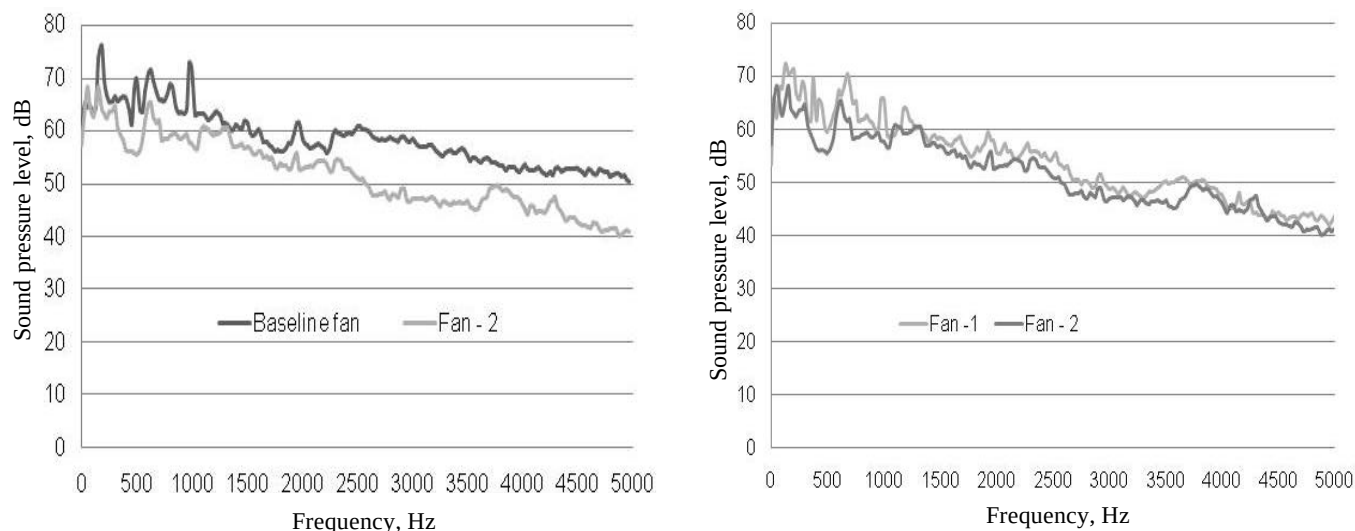


Fig. 3—Measured results between: a) Baseline fan & Fan-2; and b) Fan-1 & Fan-2

anechoic chamber. Measurement point is located 1.0 m upstream of fan inlet, with microphone aligned to motor shaft. Fan-1 and Fan-2 were tested to know their aerodynamic and aeroacoustic performances, and results were compared with baseline fan (Fig. 3).

Overall SPL for baseline fan is 82.3 dB(A), which is higher because of straight blade design producing more turbulence. Peak value (69.9 dB) is observed at fundamental blade passing frequency (BPF) of 485 Hz (Fig. 3a). Besides, another peak value (72.8 dB) is observed at first harmonic of BPF (970 Hz). A peak at impeller rotation frequency 48.5 Hz is clearly shown in Fig. 3a. Another peak is observed at 175 Hz, which could be a harmonic of shaft speed. Some of the noise peaks other than at shaft rotational frequency, BPF and their higher harmonics, could be due to resonant frequency of motor-fan casing, noise generated by electric motor, vibration due to unbalanced rotating masses.

Noise reduction of Fan-1 compared to baseline fan is 6.3 dB(A), mainly due to glass fiber, bell mouth entry at inlet, and NACA 65-010 aerofoil profile of blade geometry. Overall noise reduction of Fan-2 is 12.8 dB(A) compared to baseline fan. Fan-2 has 6.5 dB(A) further noise reduction than Fan-1 (Fig. 3b), due to using jute fiber in composite material for Fan-2, as opposed to using only E-glass fiber for Fan-1. Jute fiber is used as low density core between glass fibers. So it provides more material damping to reduce vibration noise of motor fan.

To obtain velocity profile at downstream, a three-hole Pitot probe, a Druck CE LPM 9481 differential pressure transducer, and an FLK 179 digital multimeter

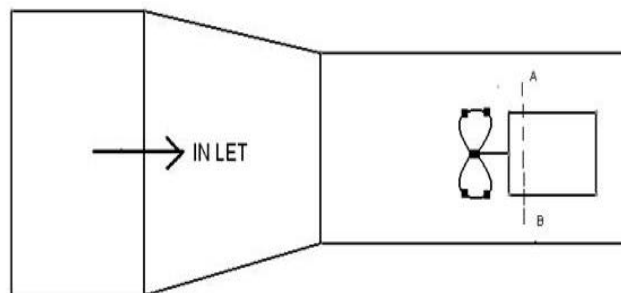


Fig. 4—Test arrangement for airflow measurement

Table 2—Noise and flow measurement results

	Baseline fan	Fan-1		Fan-2	
		SPL	NR	SPL	NR
SPL dB(A)	82.3	76.0	6.3	69.5	12.8
SPL for BPF1, dB	69.9	59.6	10.3	55.0	14.9
	(485Hz)	(340Hz)		(340Hz)	
SPL for BPF2, dB	72.8	65.6	7.2	58.0	14.8
	(970Hz)	(680Hz)		(680Hz)	
Volume Flow, m ³ /s	0.372	0.406		0.415	
		(+9.1%)		(+11.6%)	
Total pressure rise, Pa	139	96		118	
Fan input power, W	446	228		225	
Total efficiency, %	31.2	42.1		52.44	

were used. Aerodynamic performances of all fans were studied at 2920 rpm. Radial distribution of total pressure rise was analyzed at downstream of the fan. Measurements of air velocity were taken in radial direction, at a plane 15 mm behind the fan (A-B) (Fig 4).

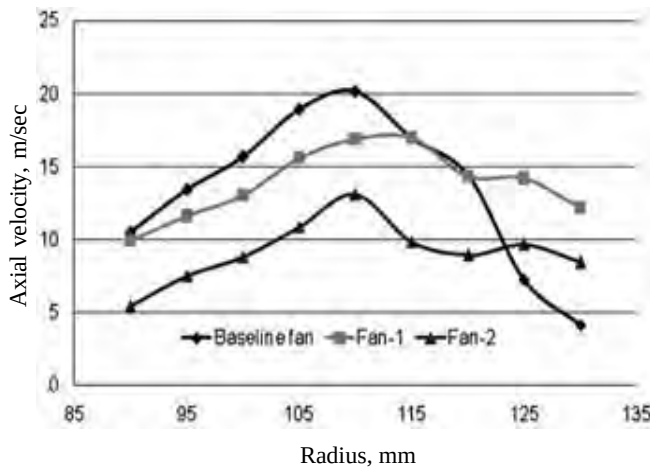


Fig. 5—Variation of axial velocity along the radius of Baseline fan, Fan-1 and Fan-2 at outlet

Fan-1 develops 9.1% more air flow than baseline fan (Table 2), mainly due to inlet bell mouth entry, and wider blade geometry. Fan-2 develops maximum flow rate; an increase of 11.6% airflow as compared to baseline fan (Table 2). Fan-1 and Fan-2 have almost same airflow rates because composite material is changed between two fans, and it is no effect on airflow rate. Variation of axial velocity along radius of Baseline fan, Fan-1 and Fan-2 at outlet (Fig. 5) indicates that maximum velocity is observed at the radius of motor (110 mm) for all three fans. This is highly desirable, as it cools motor body the most.

Conclusions

Two redesigned fans (Fan-1 and Fan-2) were fabricated using glass and jute fiber in propylene glycol resin by hand lay-up technique. A low noise and high mass flow rate motor-fan (Fan-2) was developed and confirmed by experiments. For Fan-2, overall noise

reduction is 12.8 dB(A) compared to baseline fan. Thus effect of jute fiber on noise reduction is larger than that of glass fiber, may due to low density core (jute fiber) is used in between the layers of glass fibers. So it provides more material damping to reduce vibration noise of motor fan. Mixed flow fan consisting of 7 evenly spaced blades of NACA 65-010 airfoil constant cross section, fabricated with jute and glass fiber is the best option in this case in order to reduce fan noise generation and improve cooling performance without changing fan operating point. Thus jute fibers and NACA 65-010 airfoil cross section blade can reduce fan noise significantly. Further, instead of inclined-airfoils, using curved-airfoils may still reduce the noise.

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