SANYO DENKI *AMERICA, INC.*

Fundamentals of Brushless DC Axial Cooling Fans

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1. Introduction

Brushless DC (BLDC) fans have become the most popular mode of electronics cooling in recent years. They impart kinetic energy to a localized air mass and increase the fluid velocity, which in turns increases the convectional coefficient, *h*, and increases the amount of heat removed. The fluid velocity is directly proportional to *h* through the Reynolds and Nusselt number equations. The proliferation of compact and cheap DC power supplies has relegated AC fans to the fringes of the cooling industry.

Compared to brushed DC motors, BLDC motors have various advantages, such as having easier speed control, which therefore allows better optimization of fan speed, efficiency, and acoustic performance. Brushless motors also do not have any mechanical brush contacts with the commutator, which reduces the motor temperature and increases the bearing life, and consequently the overall fan life.

Due to it's larger popularity in the Sanyo Denki product lineup, this document will mainly with axial fans. Axial fans are defined as an air-moving device where the airflow is in a direction parallel to the axis of the impeller. The air exiting the fan is imparted with energy from the rotating blades that increases the total pressure and velocity of the flow.

2. BLDC fan construction

The BLDC fan is comprised of three major sub-assemblies; the rotor, stator, and frame.

2.1 Rotor assembly construction

Figure 1. Steel rotor cup and impeller assembly, respectively.

A plastic or rubber permanent magnet strip is bonded to the interior surface of a steel rotor cup. This conducting rotor cup acts as a magnetic return path, magnet containment vessel, and also the physical interface to the impeller. The steel also provides a high mass concentration to the rotor subassembly, and therefore provides high inertia, that reduces small speed disturbances during rotation. The impeller is made of Noryl plastic, and is injection molded and glued or press-fitted onto the rotor cup. The entire rotor assembly (Figure 1) is then single or dual-plane balanced. This method of construction allows the rotor subassembly to act as a single rotating mass, which simplifies the balancing process and improves acoustical characteristics.

2.2 Stator assembly construction

Figure 2. A three-phase motor stator assembly showing the windings

Multiple pieces of steel laminates are stacked to form the core of the stator sub-assembly. Plastic insulators with contact pins fit onto the stacked laminates, and enameled copper wire is wound to create the motor poles. The shape of the stators significantly impacts the performance of the motor, and magnetic flux modeling software is used to optimize the design. Copper wire is then wound onto the stator and soldered onto pins affixed to the stator insulators. During fan operation, the stator sub-assembly is static, while the rotor-subassembly spins around it.

2.3 Frame assembly construction

Figure 3. Fan frames being arranged after injection molding

Fan frames (Figure 2) are usually injection molded from Novoloy plastic, which is an ABS+PBT mix, and are molded with a brass bushing for higher end models. This brass bushing serves to improve heat dissipation from the motor and bearings during operation. The frame can also be made of cast aluminum for standard fans above 150mm x 150mm, and also for long life, and low vibration fans.

2.4 Fan control

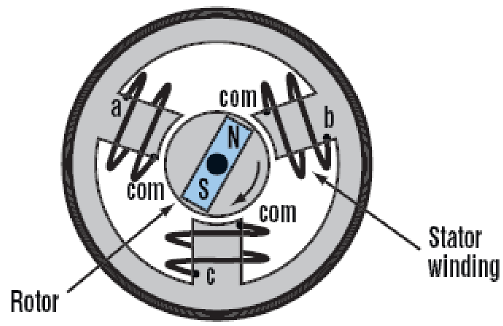

Figure 4. A simple example of a hall effect sensor operating within a motor

The basic requirement for BLDC fan control is to know the position of the rotor in relation to the stator coil at any instant. Sanyo Denki fans employ the use of Hall-effect sensors to fulfill this function. When a magnetic field is applied perpendicular to the current, it creates a potential difference (Hall voltage) on the opposite sides of the electrical conductor (copper windings) through which the electric current is flowing. Hall-effect sensors detect this voltage and translate it to a position of the rotor (Figure 3). An optional tach sensor circuit outputs 2 pulses per revolution for recording the speed of the fan. Another optional function, a pulse width modulation (PWM) circuit, allows for a control voltage input to the fan for speed regulation.

The Hall-effect sensors, and other logic components for power conditioning and drive electronics, are contained on a circular Printed Circuit Board (PCB). This PCB sits on the fan motor hub, and is visible under the fan label. Solder connections for ground and live, or the optional tach and PWM, are found on the PCB surface near the edge of the fan label.

3. Axial fan flow characteristics

3.1 Understanding the PQ curve

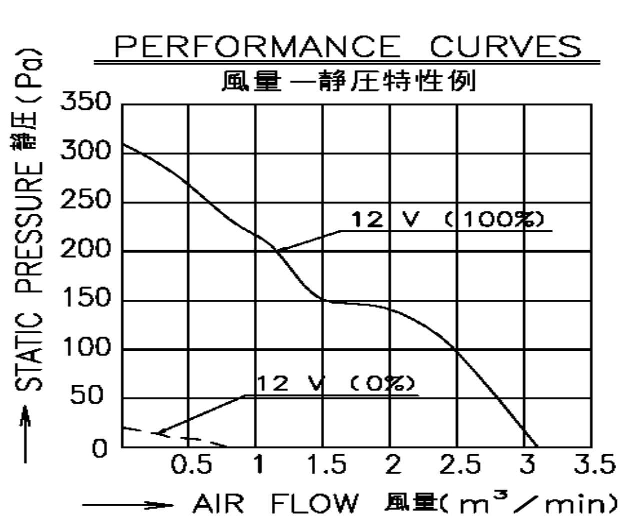

Figure 5. A typical axial fan performance (PQ) curve

A useful tool to benchmark the performance of fans is the pressure-flow, or PQ, curve (Figure 4). This curve is generated by attaching the fan to a flow bench, per the AMCA 210 standard. The fan is operated at a particular speed, and the exit orifice within the flow bench is varied from a fully obstructed, or choked, flow, to free air conditions. This variation of flow corresponds to particular pressure values, which in turn produces a PQ curve for that speed.
From Figure X, it can be seen that the axial fan PQ curves generally exhibits a degree of non-linearity. From the point of free air, any decrease in airflow results in gradual increase in static pressure.

All modern fans have blades with airfoil cross-sections, which exhibit stall characteristics, as they do in airplane wings. Once the airflow decreases to the point where the airfoil angle of attack becomes large enough for flow separation to occur, the fan stalls. From here, the lift coefficient starts to decrease, along with the static pressure. This stalling region exhibits noisy, surging and unpredictable flow, shown by the multiple airflow values for a particular pressure value. The phenomenon continues until a point where the airflow is sufficiently low for the fan blades to move air solely by centrifugal force, and this allows the static pressure to begin increasing with decreasing airflow again, until shutoff (zero airflow).

The important note from any PQ curve is the operating region for the fan, defined as the section from free air to the inflexion, or peak, in the curve. Operating the fan in this range will provide efficient and predictable performance.

3.2 Fan blade characteristics

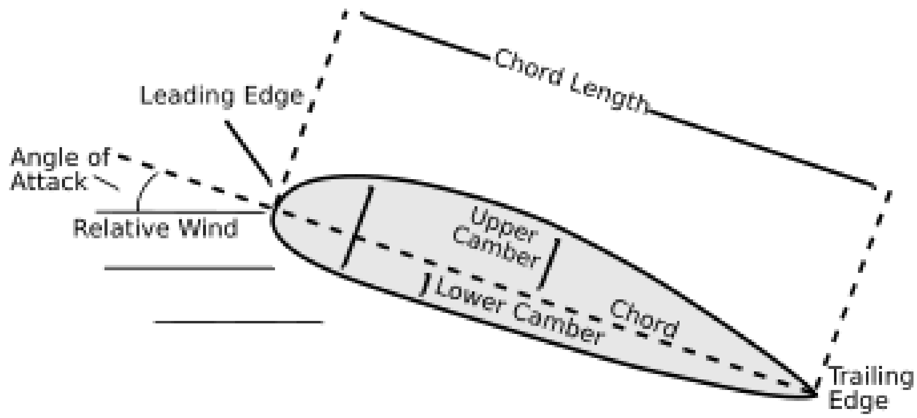

Figure 6. Airfoil cross-section and terminology

The main vehicle of energy transfer from the fan to the air is the fan blade. Characteristics to consider for fan blade design optimization are the blade angle, number of blades, and blade shape.

Varying the fan blade angle has an effect on flow rate, efficiency, and pressure generated. The main consideration for blade angle selection is the angle of attack of the blade. Generally, a shallow blade angle will cause a drop in pressure but an increase in efficiency. The same is true conversely for steep blade angles. Another option is to use backward curved blades for better efficiency, and this is more commonly seen in centrifugal fans.

The amount of static pressure produced is proportional to the number of blades multiplied by the blade width. However, fan noise is predominantly caused by blade tips, and is a large consideration when optimizing the number of blades. More blades will result in higher noise. If the number of blades is reduced, the blade width will have to increase to compensate for the static pressure. Increasing blade with also improves efficiency, but having large, wide, blades will increase the difficulty in balancing the impeller. Therefore, there must be a point of compromise for a specific design.

3.3 Fan operating noise

As previously mentioned, the number of blades has an effect on the noise produced by a fan. Additionally, a variety of other factors also affect the levels of noise produced by a fan. Here are some main causes:

i) Operating a fan in the stalling range of the PQ curve causes modulation, and a flow effect of surging back and forth. Therefore, the fan should be operated at the area of peak efficiency to have the lowest noise levels.
ii) Noise produced at the blade tips is cause by the blade hitting the air particles in the flow. Fans with high operating speeds impact these particles with higher force, thus resulting in louder noise. This is contradictory to achieving high fan performance with higher operating speeds.
ii) Poor impeller balancing manifests itself if high noise and vibration in fans. Utmost effort must be made to balance the appropriate sized impeller for the specific level of acceptable imbalance. Unbalanced fans also reduce the operating life of the bearings due to excessive loading.
iii) Single thickness blades, as opposed to airfoil cross-sections, have poor aerodynamics, and should be avoided in fan design.
iv) Having obstructions close to the fan blades will increase the noise levels.

3.4 Fan operation in parallel and series

Operating multiple fans in series or parallel within a system has different resulting cooling properties. For instance, fans in series will have the same volumetric flow as a single fan, but the exit pressure of the final fan will ideally be the overall sum of the number of fans in series. This is synonymous with a dual-stage intercooler used in automobile engines.

Conversely, multiple fans in parallel will experience the same amount of pressure head, but the combined inlet surface area of the fans leads to a corresponding combined increase in volumetric flow rate.

It is always recommended that multiple fans in a system all be of the same model. This will aid in efficiency and compatibility of the flow, while also easing the control regime all the fans.

4. Conclusion

Axial BLDC fans have made leaps and bounds in recent years to be capable of cooling the ever-increasing power dissipated by modern electronics. New fan designs that incorporate counter-rotating fans, slotted fan blades, and flow conditioning vanes continually push the envelope on convective cooling. While new cooling technologies like liquid cooling have generated some interest, the cost effectiveness, flexibility, and compactness of axial BLDC fans have made it the critical tool for thermal management.