Novel Fan Design Offers Energy Savings To Refrigeration Market

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Patented PAX Scientific™ technology applied to evaporator fans coupled with A. O. Smith motor produces significant power reduction.

Motivation

In many industries, consumer awareness, preference, and federal regulations are challenging manufacturers to develop more energy efficient products. A small reduction in the energy consumption of an electrical appliance can yield tremendous savings when used in millions of homes. In refrigeration, achieving ENERGY-STAR ® efficiency levels places a premium on developing reduced power components such as evaporator (evap) and condenser motor/fan systems. A more efficient evap stage also reduces loading on other large energy draw components in the refrigeration cycle. Thus, the power contribution of the evap component is especially important to overall refrigerator energy usage. Energy savings at the evaporator stage also afford the manufacturer greater flexibility in choosing and designing other components of the refrigeration system.

Figure 1: PAX fan for evaporator applications

While traditionally comprising an axial fan with C-frame (skeleton) motor, previous attempts to reduce evap power consumption have been costly, as evidenced by the development of the brushless DC (BLDC) motor.

Also, pressure and flow characteristics of the evap system must remain similar as energy savings are sought. If airflow is

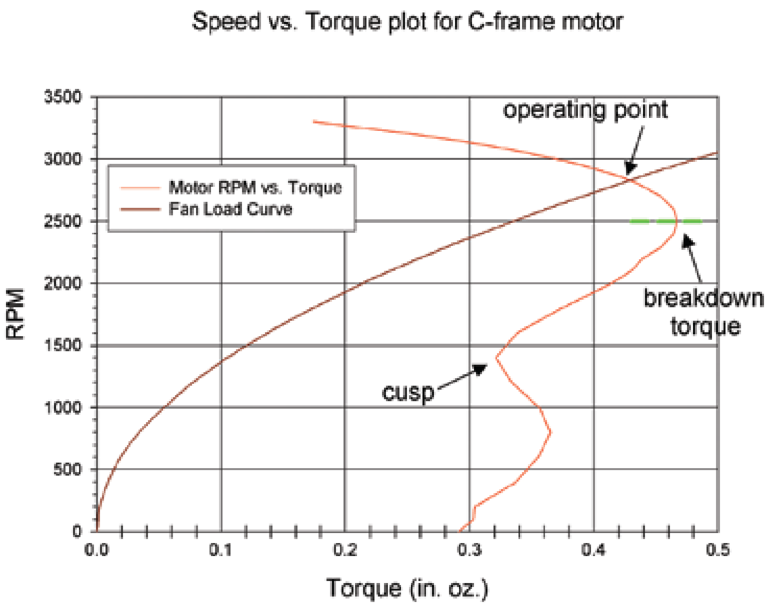

Figure 2: C-frame dyno curve with load line

too low, then interior temperatures will not be maintained without high evap run times, thereby negating any power reduction benefit. Likewise, higher airflow pushes too much cold air from the freezer compartment into the refrigerator proper, potentially causing problems such as the freezing of refrigerated vegetables.

Breakthrough in Fan Performance

Fan design is a mature technological sector wherein performance and efficiency improvements are typically minimal. A leading source of inefficiency for axial fans lies in their tendency to throw air outward, necessitating a shroud to collect and redirect airflow along the axis as intended. The Pax Group™ develops fans which employ streamlined blades with patented geometrical shapes derived from a naturalistic design approach, providing better airflow direction and improved efficiency. Potential benefits from using a more efficient PAX fan include a greater output for the same input or reductions in noise, input power, and motor size. The primary benefit sought by using a PAX fan in an evaporator application is reduced input power.

PAX Scientific develops the air-moving technologies. A. O. Smith Electrical Products Company has licensed exclusive rights from The Pax Group to use PAX fan technology in kitchen and bath applications. Figure 1 shows the PAX fan designed for evap systems that offers an efficiency improvement over other evaporator fan designs.

Matching Motor/Fan Performance

Motor design and fan blade interaction are also important factors in optimizing the performance of an evap system. AC single phase, 2 pole, 60 Hz, C-frame induction motors with a maximum (synchronous) speed of 3,600 revolutions per minute (RPM) are standard for use in these evaporator systems. A typical dynamometer curve for such a motor with important areas highlighted is shown in Figure 2. A sample fan load line is also included in the figure; the point of intersection between the motor and fan curves defines the system's operating point.

For stable, efficient operation, the operating motor speed must be above the "cusp" and preferably above the "breakdown torque" as shown in Figure 2.

Figure 3 provides a plot of efficiency vs. speed for the same C-frame motor shown in Figure 2. It can be seen from Figure 3 that this desired operating region just above breakdown typically corresponds to the region of maximum motor efficiency which is important in minimizing power input to the motor/fan system.

Both the motor and fan have design elements which can adjust operating speed and maximum efficiency ranges. Examples for the motor include wire size and number of turns and rotor end ring resistance. Hub and tip diameters and blade angles are examples of fan design elements. Evap energy minimization requires

an integrated approach to fan and motor design.
A further advantage of PAX fans is reduced air turbulence before, during, and after contact with the fan. This reduces loading on the fan. Since axial fan speed increases with decreasing back pressure, a PAX fan naturally tends to run a bit faster than its baseline counterparts. This typically improves a PAX fan's operating position on the speed-torque curve of the motor.

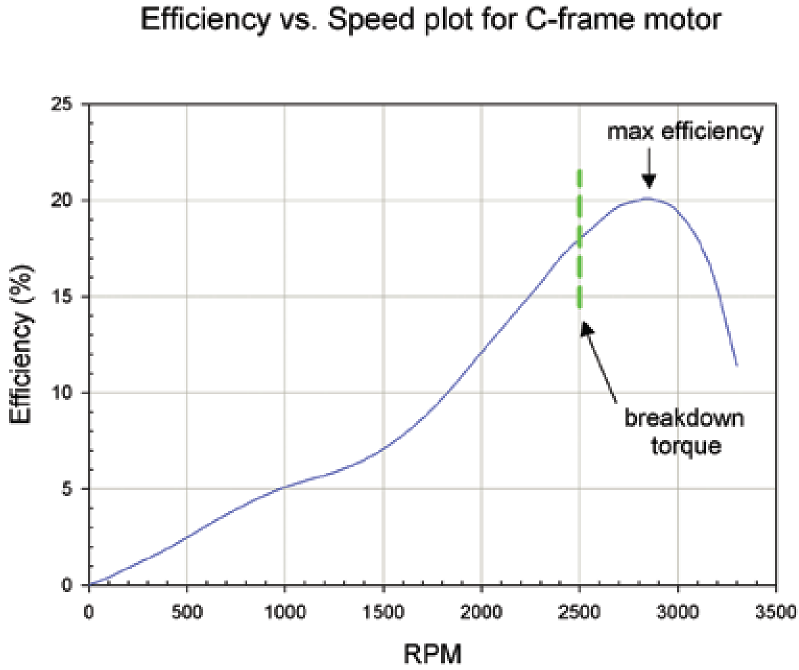

Figure 3: C-frame efficiency curve

Results - on Bench

Evaporator fans are typically either 100mm or 110mm in diameter, with the majority being 100mm. A production tooled 100mm PAX fan tests favorably when compared to a sampling of three different 100mm fan designs currently in the market. A prototype 110mm PAX fan also shows improvements when compared to a production baseline 110mm fan. Due to the aforementioned importance that closely matching pressure/flow characteristics has on refrigerator performance, specific motor matches have been developed to allow the PAX fan with a family of A. O. Smith motors to properly replace the baseline evap systems.

In all, there are four baseline systems reported here whose performance has been matched by a PAX fan/A. O. Smith motor combination, three using 100mm fans and one using a 110mm fan. The baseline systems are referred to as "Baseline 1-4." Pictures of the fans corresponding to these baseline systems are shown in figures 4-7 below. These fans are representative of what is commonly found in evap systems today.

A single 100mm PAX fan and one 110mm PAX fan are used on a variety of A. O. Smith motors to properly match performance of these baseline evap systems. These systems are referred to as "PAX/AO 1-4."

When tested on a wind tunnel flow chamber, 0.02" - 0.03" H2O of static pressure is a region commonly considered a simulation of in-unit performance for evap systems using a 100mm fan. 0.03" H2O is often chosen as the operating point with 50-60 cubic feet per minute (CFM) typically considered a desirable airflow range at that static pressure. 60-80 CFM at 0.03" H2O is typical for evap systems with 110mm fans. These are general guidelines since refrigeration systems are similar but unique. In cases where the baseline systems deviated from these guidelines, performance matches were based on test data, not the guidelines.

Data from a wind tunnel in Figure 8 shows plots of pressure and power vs. airflow for "Baseline 1" and "PAX/AO 1", both 100mm evap motor/fan systems. The PAX fan with A. O. Smith motor shows similar airflow to the baseline throughout the curve and is nearly identical around the operating region (0.03" static). Also, a considerable reduction in motor/fan power required is noted throughout the curve. Tests were run at 115 volts and results are corrected to standard temperature and pressure. Both motors have 3/8" lamination stack heights.

Table 1 is a summary of discrete data taken from Figure 8. At the rated pressure and airflow the

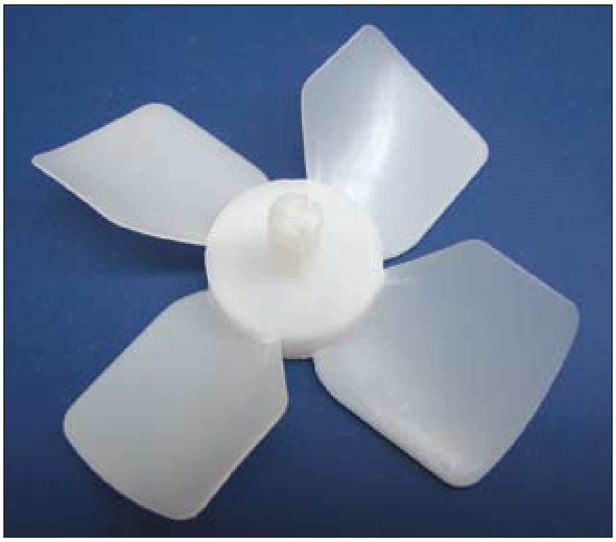

Figure 4: Baseline 1

Figure 5: Baseline 2

PAX/AO system shows a power reduction of nearly 23% over the baseline.

Table 2 summarizes sound levels measured in a semi-anechoic chamber with the motor/fans mounted in evaporator panels and hung from supports, running in free air at 115 volts. The PAX fan is quieter than the baseline even though it runs slightly faster. Noise from the evaporator is typically not critically important since the panel is mounted inside the freezer compartment.

Two other baseline 100mm fans were tested with a PAX/A. O. Smith motor created for each. Test results at 115 volts are summarized in Table 3.

In the case of "Baseline 3," the manufacturer is using a stronger 1/2" stack motor to drive considerable airflow (62.7 CFM) out of the 100mm fan. The corresponding PAX/AO system was also developed with a 1/2"

Figure 6: Baseline 3

Figure 7: Baseline 4

1 Tognazzini, Bruce, Apple Computer Inc. TOG On Interface, Addision-Wesley Publishing Company, Inc. July 1993, pg. 96.

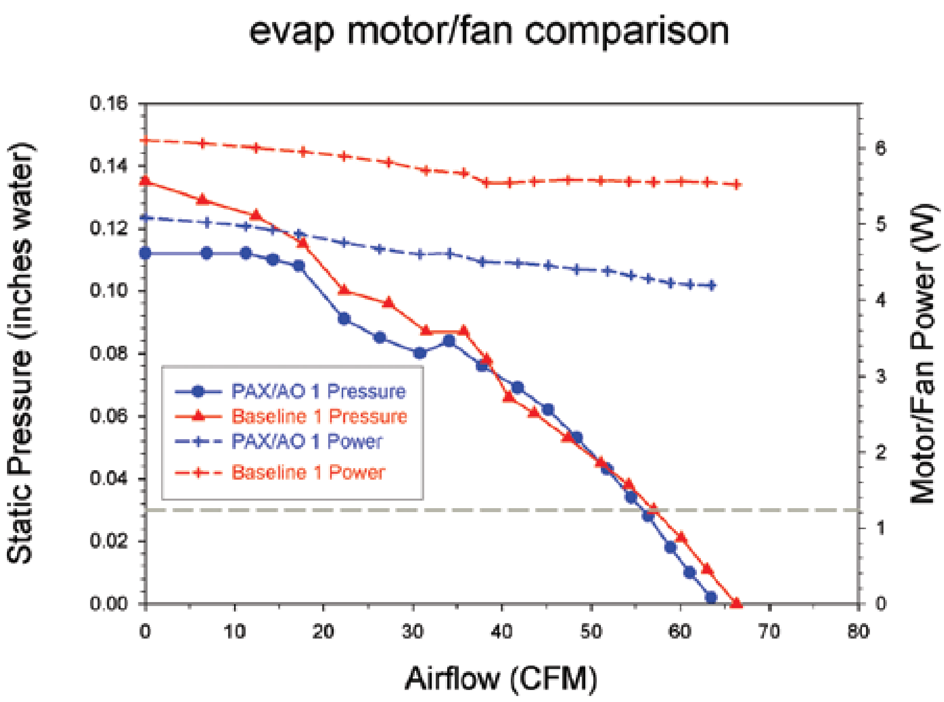

Figure 8: Wind tunnel Performance Comparison - Baseline 1

stack motor. All other motors referenced in this paper have a 3/8" stack height.

Table 4 shows preliminary data of the prototype 110mm PAX fan with A. O. Smith motor compared to its 110mm baseline counterpart, "Baseline 4." Initial results look promising as the PAX fan with A. O. Smith motor has similar output but uses 36% less power. The "PAX/AO 4" system was tested at 87 volts and a new motor is being designed that will provide the same electro-mechanical performance at 115 volts, maintaining the power savings.

motor/fan	Static Pressure (inches H_20)	Airflow (CFM)	Power (W)	RPM
Baseline 1	0.03	57.0	5.56	2,661
PAX/AO 1	0.03	55.8	4.29	2,943

Table 1: Data from Wind tunnel - Baseline 1

motor/fan	RPM	Sound Power (dBA)	Sound Quality (sones)
Baseline 1	2,517	41.4	0.43
PAX/AO 1	2,710	39.5	0.33

Table 2: Sound Comparison - Baseline 1

motor/fan	Static Pressure (inches H_20)	Airflow (CFM)	Power (W)	RPM	Motor Stack Height (inches)
Baseline 2	0.03	46.9	5.51	2,690	3/8
PAX/AO 2	0.03	47.2	3.97	2,736	3/8
Baseline 3	0.03	62.7	6.17	3,155	1/2
PAX/AO 3	0.03	63.0	5.46	3,347	1/2

Table 3: Data from Wind tunnel - Baselines 2 and 3

Results - in Unit

Power savings noted through bench or wind tunnel testing is encouraging but the ultimate value of a reduced power evap system is found in total energy savings of the refrigerator. Refrigerators can be tested for daily energy consumption using ASHRAE Standard 117-1992, "Method of Testing Closed Refrigerators." Freezer and refrigerator compartments are maintained at specified temperatures while total energy used by the refrigerator is recorded in kW-hours/day. In a single unit three day test conducted in the A. O. Smith laboratories the "PAX/AO 1" system reduced daily energy consumption over "Baseline 1" by 3.9% (see Table 5).

This is especially significant considering that there are other components contributing to

motor/fan	Volts	Static Pressure (inches H_20)	Airflow (CFM)	Power (W)	RPM
Baseline 4	115	0.03	61.7	6.66	2476
PAX/AO 4	87	0.03	61.7	4.25	2420

Table 4: Data from Wind tunnel - Baseline 4 - 110mm fans

motor/fan	Average Daily Energy Consumption (kW-hours/day)
Baseline 1	1.028
PAX/AO 1	0.988

Table 5. Refrigerator Energy Consumption Results per ASHRAE Std. 117-1992

the overall energy consumption of the refrigerator. Additional testing needs to be done in each application to quantify in-unit savings.

Summary

Refrigerator manufacturers are continually looking for ways to reduce energy consumption in their products. The evaporator system is an important component of this energy use. With the application of a more efficient motor/fan design, evaporator performance can be maintained while input power is reduced. PAX Scientific develops fluid moving devices with substantial improvements in efficiency whose designs are based on naturally occurring systems, and A. O. Smith motor designs have been developed which tune the operating point of the motor/fan system to maximize efficiency. Optimizing evaporator power reduction requires careful matching of the motor/fan system; ideally during operation both the fan and motor would be running at their maximum efficiency point. Preliminary test results indicate that one such evaporator system of PAX fan with A. O. Smith motor, when compared to a currently produced evap assembly, reduces evap input power by nearly 23% and overall refrigerator energy. usage by 3.9%.