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COOL RUNNING DC UAV MOTORS

By Paul Lew, president, Lew Aerospace

Using an electric motor to power the Inventus E, an unmanned aerial vehicle (UAV), requires system component optimization, including motor efficiency, battery power and weight and thermal loading. When we first started using electric drives motor failures were a problem. For three years, the best *mean time between operational mission failure* (MTBOMF) of the motors - was 15 hours of flight time, or about 15-20 flights. Most of the flights achieved a much lower MTBOMF of 3 or 4 hours. This meant we were unable to reach reliability targets with the geared brushless DC (BLDC) motors we had been evaluating. Finally, we began testing direct drive motors from ThinGap Corporation.

We tested 25 ThinGap brushless motors on several different classes of aircraft and the tests are still in progress. As of the writing of this article, we have achieved 500 hours of operation with one motor, 300 hours and 200 hours, the motors continue to operate and none of the 25 ThinGap motors has failed on any of our aircraft.

The Inventus E electric UAV is a robust flying wing platform developed for detailed low altitude reconnaissance. Autonomous flight capabilities include autonomous take-off and landing, catapult or air launch from a minimal clear area, manual parachute recovery system and live downlink video cameras. The Inventus E features a cruise speed of 44 mph (battery life 120 minutes), maximum speed of 85 mph (battery life 20 minutes), range of 90 miles and altitude of up to 10,000 ft.MSL.

Conventional motors can fail at high ambient temperatures but the ThinGap motors seem to be immune to their effects. We design and manufacture in Las Vegas and use a dry lakebed used for testing. In July, ambient air temperatures often reach 120°F. The temperature of an Inventus E waiting on the runway can exceed 160°F. When the BLDC motor stator runs at full power, such as for takeoff, the combination of ambient temperature and motor-generated thermal loads can cause magnets to demagnetize and windings to burn, leading to premature motor failure. The ThinGap motors have

The Inventus is a state-of-the-art reconnaissance system packaged in a highly efficient, highly stable flying wing constructed from composite materials. Able to fly manually or autonomously, the Inventus E offers a line-of-sight real-time video and flight line.

continued to operate in these conditions without problems.

Causes of Overheating

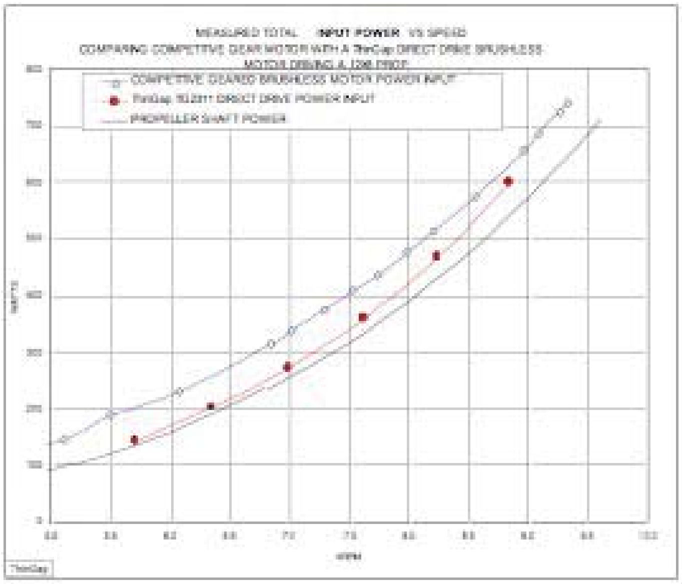
Motors overheat when the magnets become too hot and the motor torque constant is reduced. This causes current to increase thereby causing a large increase in I2R losses. Overheating can be caused by too much loss in the copper of the motor. High altitude does limit motor heat dissipation where the cooling properties of air are much less effective due to the lower density of the air.

More often, a motor overheats because of misapplication. The heavier the load on a motor the more heat generated from current induced I^2R. In fact, the leading cause of motor failure from overheating is a result of running at higher loads than the motor ratings, for example, using an undersized motor. This has become more commonplace as concern for energy efficiency and vehicle weight puts the emphasis on eliminating oversized motors.

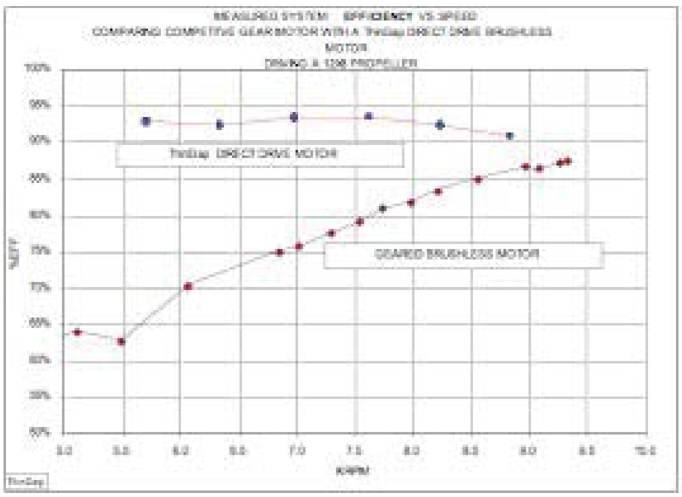
Most electric motors reach peak efficiency at 80% load. When the load is higher, such as climbing, the motor becomes less efficient and can use more energy than the correct or larger size motor. In effect, under sizing a motor uses more energy.

Typical Motor Design for Small Vehicles

Typical hobby motors are designed to use high



Comparison of input power versus speed of motor and 12 x 8 propeller for a conventional BLDC motor with geared drive and direct drive ThinGap BLDC motor.

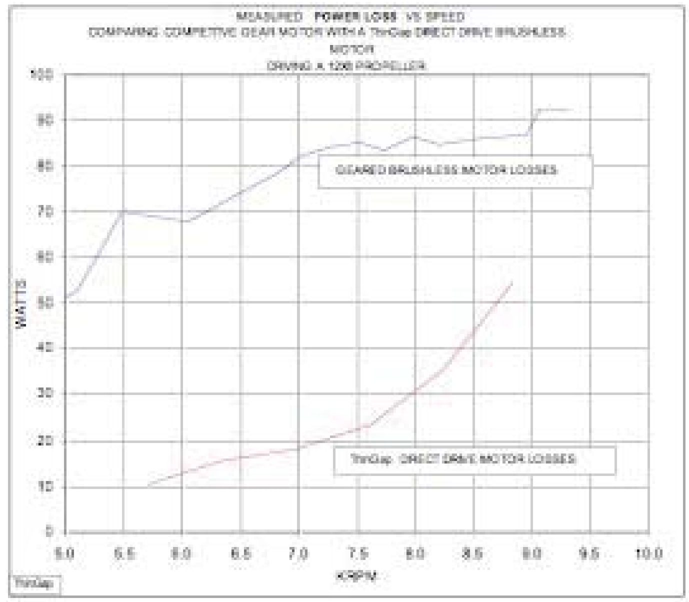


Comparison of power losses in a geared motor with the losses in a ThinGap motor when driving a 12 x 8 propeller

speeds to generate power, since RPM x Torque = Power. These motors operate at 50,000 RPM and utilize gearboxes to reduce the speed and torque to usable levels. The high speed causes eddy current heating in the laminations of the motor. Regardless of how much copper is wound into the motor to reduce the I^2R losses, the high speed can overheat the magnet structure in seconds. Efficiency peaks at maximum power on these geared motors but typically the efficiency suffers when cruise power is required, thereby limiting the battery life (<u>see chart</u>) These charts include the losses of the gearbox which can be considerable when turning at 50,000 RPM.

ThinGap Motor Construction

The ThinGap coil is mounted directly to an aluminum structure that provides an excellent conductive heat path to the mounting surface. This, and because both sides of the coil are exposed to air and have dual radiation surfaces, provides excellent cooling capability for the motor. Excellent heat dissipation capability coupled with high efficiency reduces the amount of heat generated, allowing the motor to run cooler.



System (motor and Controller) efficiency versus speed for the ThinGap direct drive BLDC motor and conventional BLDC gearmotor.

The inside and outside surfaces of the coil are exposed to moving air inherently pumped into the gap by the rotor. This air movement effectively dissipates more heat allowing the use of more current without overheating the motor. There are no laminations or iron core in the ThinGap motor. By eliminating the iron core, eddy current and hysteresis losses are eliminated and efficiency is improved. The ThinGap motor has all the magnetic circuit rotating together. The rotor has more inertia because of this construction. This higher inertia reduces vibration and without the gearbox produces power with very little noise. These characteristics combined with very low harmonics enable the motor to deliver very smooth velocity with quiet and cool operation.

The low heat gain, a secondary benefit of the low-loss design, allows intermittent (such as battery powered) performance at a high-energy conversion level and high power input. The efficiency of the motor remains high over a wide performance range.

We use a fairly standard speed controller, except it is exceptionally light, very reliable and handles the required voltage and current. We use the TG 2300

ThinGap motors to power the 12 x 8 props of the Inventus E at close to 10,000 RPM.

We were able to get some other motors to run under the same operating conditions, but they performed poorly and failed prematurely. The ThinGap motor operated the same whether the ambient temperature was 60ºF or 120ºF without any failures. Additionally, we have flown the aircraft in heavy rainstorms and found the motor is unaffected by water.

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